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COMMUNITY NOISE EXPOSURE RESULTING FROM AIRCRAFT OPERATIONS: ACQUISITION AND ANALYSIS OF AIRCRAFT NOISE AND PERFORMANCE DATA

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This report is one of a series describing the research program undertaken by the Aerospace Medical Research Laboratory to develop procedures for predicting community noise exposure resulting from aircraft operations. This report outlines the acoustic measurement test conditions, the acoustic data reduction and interpretation procedures, and the type of aircraft performance information needed to obtain a noise data file for pre-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) dicting the noise produced by aircraft operations. The procedures result in the descriptions of the noise of an aircraft in terms of the effective perceived noise level, the sound exposure level and several other noise measures. Level flight measurements and static engine noise tests are described, which are applicable to conventional fixed wing aircraft and helicopters.

The noise data are to be acquired under controlled conditions with accuracy requirements generally similar to that required for civil aircraft noise certification. Primary interest is in predicting aircraft noise levels at distances greater than 150 feet from the aircraft. The test procedures do not assume or require elaborate ground or aircraft test instrumentation. However, where convenient, the test procedures may be modified to take advantage of these refinements.

PREFACE

The authors gratefully acknowledge the many helpful technical discussions and critical reviews of measurement procedures by the contract monitor, Jerry D. Speakman, and by John N. Cole of the Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The revised procedures presented in this report have benefited from the analyses and comparisons of noise data acquired and processed by the Air Force following initially-proposed test procedures.

This report is one of a series describing the contractual and in-house research program undertaken by the Aerospace Medical Research Laboratory under Project/Task 723104 "Measurement of Noise and Vibration Environments of Air Force Operations", to develop procedures for predicting community noise exposure resulting from aircraft operations. The companion reports are listed as references 5, 6, 7, 8, and 9. The Air Force Weapons Laboratory provided funding to partially support this development program.

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DEFINITIONS OF SYMBOLS AND TERMINOLOGY

Symbols appearing throughout the test plan are consistent with those described in Section A36.4 of Part 36, Federal Aviation Regulations. A number of additional symbols have been used to assist in the analysis. To differentiate among quantities, events, locations, or averages, various subscripts and primes have been used. In the following definitions these modifiers to symbols have been suppressed when the meaning would be obvious.

The structure for subscripts is as follows:

1. An Arabic numeral identifies an event in time or a linear dimension associated with that event.

2. A subscript "f" indicates a noise measurement obtained in the field without adjustment to reference conditions.

3. A subscript "j" indicates a running index associated with measurements on specific flights, where "j" indicates the flight number.

4. The subscript "i" is a running index associated with any one band in the set of one-third octave frequency bands.

5. A variable with a superscript apostrophe (read as "prime") identifies a value of the variable intermediate in the process of determining the final value adjusted to reference conditions.

6. A subscript "ref" indicates the value of a variable at its reference condition; subscripts "c", "o", and "r" also indicate reference conditions.

Time

$\Delta\tau$ time increment between noise measurements of the same fly-over at two different locations.

Geometry

K point on ground directly below flight path where a noise measurement is performed.

Q point on flight profile at time of PNLM.

L point on ground to one side of flight track.

X point on flight profile at time of PNLM.

d perpendicular distance from point L to flight track.

h height of aircraft above ground.

x arbitrary distance

S slant distance from L to flight profile -- "distance of closest approach".

θ directivity angle for PNLM.

ϕ polar angle about aircraft, on the ground, measured from the forward direction of the aircraft.

γ climb angle of aircraft.

Speeds

v aircraft speed in feet per second.

V aircraft speed in knots.

c speed of sound in air.

Acoustical

AL A-weighted sound level, in dBA, as specified in IEC Publication No. 179.

ALM Maximum A-level occurring during a noise event.

Acoustical (Continued)

ALT	Tone-corrected A-weighted sound level in dB, defined as: $$ALT = AL + C$$ $$(\text{or } ALT = AL + PNLT - PNL)$$
ALTM	Maximum tone-corrected A-level occurring during a noise event.
C	Tone correction, in dB, calculated in accordance with ISO recommendation R507, June 1970 or later revision.
D	Duration correction, in dB, defined as: $$D = EPNL - PNLTM$$
dB	Decibel.
D-level	D-weighted sound level, in dBD, as specified in SAE ARP 1060. (For many flyover signals, the following approximation holds: PNLM = D-level + 7).
EPNL	Effective perceived noise level, in EPNdB, calculated in accordance with FAR Part 36.
f	Frequency in hertz.
k	A running integer identifying the noise levels determined at the k-th interval of time from an arbitrary reference time zero of the flyover signal.
PNL	Perceived noise level in PNdB.
PNLC	Composite perceived noise level, computed from the maximum levels reached in each one-third octave frequency bands during a flyover.
PNLM	Maximum perceived noise level as defined in FAR Part 36.

Acoustical (Continued)

PNLT	Tone-corrected perceived noise level, where $PNLT = PNL + C$
PNLTM	Maximum PNLT occurring during a noise event.
PWL	Sound power level in dB re 10^{-12} watts.
SEL	Sound exposure level, in dB, as defined in "Draft Report on Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure", prepared by Task Group 3, H.E. Van Gierke, Chairman, for the Environmental Protection Agency Aircraft/Airport Noise Report Study, June 1973. The sound exposure level is the level of the time-integrated mean square A-weighted sound pressure for an event, with a reference time of one second:

$$SEL = 10 \log \int_{-\infty}^{+\infty} 10^{\frac{AL}{10}} dt$$

For purposes of aircraft noise evaluation, SEL is computed from A-levels sampled at discrete intervals of 0.5 seconds or less. Thus the working expression for SEL becomes:

$$SEL = 10 \log \sum_{k=0}^{k=\frac{d}{\Delta t}} 10^{\frac{AL(k)}{10}} + 10 \log \Delta t$$

where d is the time interval during which AL(k) is within 10 dB of the maximum A-level, and Δt is the time interval between noise level samples.

Acoustical (Continued)

SEL (Continued)

Note that the SEL is identical to the single event noise exposure level (SENEL), in dB, as defined in "Noise Standards, Title 4, Subchapter 6, California Administration Code", 1970, except that the SENEL is defined in terms of integration (summation) from a threshold noise level approximately 30 dB below the maximum level, while, in this report, SEL is defined in terms of integration over noise levels within 10 dB of the maximum value. However, integration over only the upper 10 dB yields acceptable values that typically differ by 0.3 dB or less from values based on in tegration over 30 dB.

SELT Tone-corrected sound exposure level, in dB, defined for a noise event as:

$$SELT = 10 \log \int_{-\infty}^{\infty} 10^{\frac{ALT}{10}} dt$$

For purposes of aircraft noise evaluation, SELT is computed from tone-corrected A-levels sampled at discrete time intervals of 0.5 seconds or less, as follows:

$$SELT = 10 \log \sum_{k=0}^{k=\frac{d}{\Delta t}} 10^{\frac{ALT(k)}{10}} + 10 \log \Delta t$$

Acoustical (Continued)

SELT (continued)

where d is the time interval during which ALT (k) is within 10 dB of ALTM, and Δt is the time interval between noise level samples.

SPL Sound pressure level in dB.

α Sound attenuation coefficient in air.

ξ Excess sound attenuation near the ground.

Δ Adjustment factors to reduce test conditions to reference conditions.

Engine Performance

F Net thrust in pounds.

s Standard deviation using unbiased degrees of freedom.

$t_{\alpha/2}(n-1)$ t statistic used in determining confidence intervals.

n Number of events or samples.

1. INTRODUCTION

The measurement and analysis procedures described in this test plan are designed to obtain the information necessary to describe the noise produced on the ground by an aircraft in the vicinity of an airport. The noise exposure forecast (NEF) procedure methodology requires a description of the noise of an aircraft in terms of EPNL as a function of slant distance to the aircraft for different engine power settings, and a description of the takeoff and landing profiles used by the aircraft under different operational conditions. In a similar manner, computation of the day/night average level*(DNAL) requires aircraft noise descriptions in terms of the SEL noise measure. The test procedures are specified to obtain this information for both air-to-ground sound propagation and for ground-to-ground sound propagation.

This plan outlines the test conditions, acoustic data reduction and interpretation procedures, and also describes the type of aircraft performance information needed. Aircraft performance information is assumed to be available, or derivable, from aircraft performance data given in flight manuals or obtainable from the airframe manufacturer.

Two basic types of noise measurement tests are described:

1. Flyover noise tests, for acquiring noise information for aircraft in flight (takeoff, landing, etc.).

2. Static engine runup tests to provide information on noise levels during ground maintenance operations.

* As defined in Public Health and Welfare Criteria for Noise, EPA report 550/9-73-002 dated 27 July 1973.

A third basic type of noise measurement, runway sideline measurements during aircraft takeoffs or landings, may also be required to fully describe the noise of aircraft operations. However, the interpretive procedures for handling sideline noise data to produce reliable noise procedures are still under investigation. Hence, sideline test procedures have been omitted from this report.

Flyover noise test data will be needed for all aircraft of concern. Engine runup tests may be omitted for some aircraft, depending upon the aircraft noise characteristics and modes of operation. Table I lists the suggested priority of testing for Air Force aircraft.

The tests are detailed to apply to conventional fixed-wing aircraft and to helicopters. Modification in test procedures and measurement locations may be needed for measurement of some types of V/STOL or non-conventional aircraft.

The noise tests are to be conducted only under a restricted range of weather conditions, and normalized to standard day condition (59° F, 70% relative humidity). Sufficient noise and aircraft performance data are to be obtained to permit estimation of noise and performance characteristics under varied weather conditions and airbase altitudes.

The noise data are to be acquired under controlled condition with accuracy requirements generally similar to that required for civil noise certification. However overall accuracy requirements do not necessarily coincide with that required under FAR 36, and somewhat lessened accuracy in terms of repeatability in data is acceptable. This relaxation results from the intended use of the information, that of estimating noise levels for ranges of operations where precise weather conditions and operational procedures and configurations are not known.

TABLE 1

SUGGESTED PRIORITY FOR AIR FORCE NOISE MEASUREMENTS

AIRCRAFT FLIGHT TESTS

Jet Aircraft:

F4
F100, F101, F102
F111
T38
T33
T37, A37
KC135A
F105D, F106
B52C, F, G
C141
C5A
F104
B57
A7D
B52H

Propeller Aircraft:

C123, C123K, C119, C121
C130
C97, C124
C7, C54
C131, C118, T29
OV10

Helicopters

H-1
H-43
H-34
H-3
H-53

NOTES

Priority listing for the aircraft was determined by the number of each type (or similar type) in Air Force service in July 1971, and consideration of noise characteristics.

Aircraft with the same or similar engines and performance have been grouped together, and in most cases, any aircraft in the same group may be measured as convenient. The several exceptions are underlined. Thus, the F105D is preferred because it is the only model with water injection, and the C123K is preferred because it has auxiliary jet engines.

Expected service life, projected changes in inventory, and noise characteristics may influence the aircraft measurement priority. For example, the T-33 may have reduced significance due to its relatively low noise output, and perhaps the C5A should be assigned a higher priority because of its expected future service life.

Noise data are to be acquired on magnetic tape with subsequent analysis in terms of one-third octave band noise spectra. Effective perceived noise levels (EPNL) and tone-corrected perceived noise levels (PNLT) are to be calculated from the one-third octave band data as appropriate. Other noise measures also may be calculated. Noise measures of particular interest include the perceived noise level (PNL), A-level and the sound exposure level (SEL).

The primary interest is in predicting noise levels at distances greater than about 150 feet from the aircraft. Generally, the noise measurements will be in the "far field" of the source. Thus, the measurements will not supply the information needed for predicting hearing damage hazards for personnel near the aircraft.

These procedures do not assume nor require elaborate or special ground and aircraft test instrumentation. Thus the tests do not assume the availability of special flight test instrumentation in the aircraft, continuous ground tracking facilities (tracking camera or radar) or availability of continuous time signals. Where convenient, the test procedures may be modified to take advantage of these refinements, thus adding to test accuracy and possibly allowing some simplification in test planning.

The several appendices to this test plan discuss the background for certain measurement and calculation approaches adopted in the test plan or provide derivations for some of the calculation steps. Appendix A, for example, discusses the rationale for reliance on level flyover tests for obtaining noise information for takeoff and landing operations. Several of the appendices discuss recommendations given in this test plan, which are based upon analysis of noise data acquired in accord with initial drafts of this test plan.

2. ACOUSTIC MEASUREMENT EQUIPMENT

Measurement equipment should meet the application requirements of FAR Part 36, Section A36.2 (b) and (c). Acoustic data processing equipment should meet the requirements of FAR 36, Section A36.2(d), with the exception of changes in sampling intervals and integration times noted in Section 6 of this test plan.

3. METEOROLOGICAL CONDITIONS AND MEASUREMENTS

Tests should be conducted under meteorological conditions meeting the requirements of FAR Part 36, Section A36.1 (b) (3) as follows:

a. No rain or other precipitation.

b. Relative humidity not higher than 90% or lower than 30%.

c. Ambient temperatures not above 86° F and not below 41° F at 10 meters above ground.

d. Airport reported winds not above 10 knots and crosswind component not above 5 knots at 10 meters above ground.

e. No temperature inversions or anomalous wind conditions that would significantly affect the noise level of the aircraft at the noise measurement positions.

Generally, we anticipate that the tests would be conducted in the vicinity of a permanent meteorological facility that would provide hourly sequence data representative of conditions near the geographical area in which the noise measurements are made. The minimum hourly sequence data to be reported include the temperature, relative humidity, barometric pressure, wind direction and magnitude. In addition, the wind magnitude, temperature and relative humidity should be measured near the microphone at each measurement position at hourly intervals, or more frequently during the test periods.

The minimum check for determining possible inversions or anomalous wind conditions should consist of inspection of available radiosonde data and comparison of surface temperatures with an outside air temperature measurement acquired by the flight test airplane.

4. GENERAL TEST CONDITIONS

The general test conditions are similar to that specified in FAR Part 36, Section A36.1 (b) (2). Measurements should be conducted over a relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted or tall grass, shrubs, or wooded areas.

a. For flight test, no obstructions that would significantly influence the sound field should exist within a conical space above the measurement position, the cone being defined by an axis normal to the ground and by a half angle of 75° from this axis.

b. For ground tests, no obstructions that would significantly influence the sound field should exist between the microphone and the aircraft within a horizontal angle extending 60° to either side of a horizontal line between the microphone and the aircraft or to either side of a horizontal line perpendicular to the aircraft ground track and the microphone.

The ground surfaces should be similar within a 15 foot radius about each measurement station. Hard surface is preferred.

5. CONVENTIONAL AIRCRAFT FLIGHT TESTS

Aircraft flight tests are planned so that all needed noise information for predicting noise levels for all normal flight operations can be obtained from a set of controlled level flight flyovers. Supplemental noise level measurements during actual approach and takeoff operations may be added but are not felt to be essential for conventional aircraft. Appendix A discusses the rationale for relying on level flight flyovers.

The noise data are to be acquired during level aircraft flights for a range of engine thrust conditions. The flights are to be conducted at either 400 feet AGL (above ground level) for low power runs or 1000 feet AGL for high engine power runs. Two runs are to be made at each test condition. The runs may be in alternate (180°) directions if air traffic conditions permit; or, the two runs may be made in the same direction, if more convenient from air traffic control considerations.

Aircraft altitudes (up to a maximum height of 1000 feet AGL) and airspeeds should be selected so that the duration of the flyover signal* is in excess of five seconds. Figure C-1 of Appendix C provides estimates of signal duration as a function of the ratio of flight height AGL to flight speed, as based on recent flight test measurements. Should it not be feasible to obtain flyover signal durations of five seconds or more, data processing sampling intervals and integration times must be shortened (see 6.2).

The aircraft should fly directly over two ground microphone positions located underneath the flight path, approximately 1000 feet apart. In addition to the two microphone positions directly

*Duration is defined as the time, in seconds, that the flyover noise signal is within 10 dB of PNLTM or ALTM.

underneath the flight path, one microphone should be placed on each side of the centerline at a distance of 500 feet.* The aircraft is to maintain a constant heading and constant altitude over the two microphone positions, and for distances of 1.5 n miles both preceding and following passage over the microphone locations.

The tests should be conducted at a constant engine thrust (power), altitude and airspeed. Under some conditions it may not be possible to hold these conditions for level flight along the entire flight track. In such cases thrust and altitude should be maintained, and airspeed varied as necessary. The flights should be conducted at airspeeds approximating those encountered for the appropriate takeoff, landing, or climb operation. The aircraft may use drag-producing elements (i.e., landing gear, flap, spoilers, etc.) as needed to help maintain a constant speed.

Selection of thrust conditions should be governed by consideration of the engine thrust and aircraft operations likely to be employed within 15 to 20 miles of an air base. Test conditions should cover the range of engine thrust conditions typically employed, with overlap, if necessary, to permit extrapolation to cover hot day conditions, or takeoffs and landings at 5000 feet pressure altitudes. As a minimum, test engine thrust conditions should include four conditions:

a. Takeoff at full thrust.

b. Takeoff at thrust equivalent to that of 100° F day.

c. Landing thrust at near minimum (structural) weight.

*Appendix B discusses the reasons for omitting noise measurements at large slant distances.

d. Landing at maximum landing weight.

For most aircraft, tests at representative climb power thrust should be included.

5.1 Aircraft Information

It will be assumed that only the standard aircraft cockpit instrumentation is available during the field tests. Basic aircraft information, exclusive of engine information, needed for each run will include:

- indicated airspeed
- pressure altitude
- outside air temperature
- flap, spoiler and landing gear configuration
- operating gross weight

The engine information to be observed and reported may vary with type of engine and available instrumentation. Prior to each test, a review of available flight manuals and engineering data should be undertaken to determine the procedures for utilizing and correcting cockpit instrumentation to estimate the net thrust (in case of a turbojet aircraft) with appropriate engine or shaft RPM information. For a straight turbojet engine, the needed information will typically include: engine RPM, engine exhaust pressure ratio, engine exhaust gas temperature, and engine fuel flow. For fan engines, fan speed should be noted.

Continuous recording of aircraft information during the level flights, while desirable, is not essential. Test reporting procedures should be worked out with the flight crew so that the needed information can be noted by the pilot or observer after stabilization prior to beginning the run, and immediately following the run.

5.2 Radio Communications

Two-way radio communication is needed between the aircraft and the two microphone stations under the flight track. Radio receivers only are required at each of the two microphone stations to the side of the flight track.

5.3 Time Synchronization

The aircraft position must be related to the noise recorded at the ground measurement locations by means of time synchronization signals. Synchronization signals will be used primarily to determine the time as the aircraft passes overhead (or nearest) the ground measurement position and to establish the angles of maximum sound radiation from the aircraft.

Satisfactory time synchronization can be established by use of voice synchronization signals transmitted from one "master" ground station to the aircraft and to other stations prior to each run. The procedure might follow this sequence:

a. The aircraft would notify the ground stations several miles before reaching the start of the test run.

b. The master ground station transmits a "standby" signal to aircraft and other stations; tape recorders are activated on this signal and personnel are also alerted for start of stopwatches.

c. The master ground station gives a "mark" voice signal which is recorded on tape at all stations. Stopwatches also are activated on this signal. This signal also serves to alert the aircraft for observation of aircraft data.

d. Just prior to the aircraft overhead the ground station transmits "standby to mark ." Then, when the aircraft is overhead, "mark" is transmitted. (These voice signals are not recorded on tape.) The aircraft conditions are to be noted by flight crew at this point and each ground station stops its watch on the "mark" signal.

Only the first "mark" voice signal is recorded on tape. Time intervals determined from the stopwatches are used to determine the time at which the aircraft is overhead.

5.4 Height Determination

The height of the aircraft above the ground as it passes over each of the stations under the flight path is to be established by photographic scaling of aircraft from photographs taken at the two stations as the aircraft passes closest to the stations.

5.5 Repeat of Flights

Aircraft flights should be repeated if there is a suspicion of faulty recording of data, lack of time synchronization at stations, or noticeable deviation of aircraft flight track, altitude or intended operating conditions.

5.6 Noise Data Tabulation

The following data are to be obtained and tabulated for each station and run:

a. $EPNL_f$, $PNLTM_f$, $PNLM_f$, SEL_f and $SELT_f$.

b. One-third octave band noise spectrum at the time of PNLM, $SPL(\theta)_{if}$.

c. The following quantities calculated from $SPL(\theta)_{if}$: $PNLT(\theta)_f$ and $ALT(\theta)_f$. Note that $ALT(\theta)_f = AL(\theta)_f + C(\theta)_f$ and $C(\theta)_f = PNLT(\theta)_f - PNLM_f$).

d. Time interval between the time at which the aircraft was overhead (or time of nearest approach) and time at which PNLM was observed.

e. Distance to aircraft at time of closest approach.

f. Surface temperature and relative humidity.

6. NOISE DATA PROCESSING

Noise data processing should utilize equipment which meets the requirements of FAR 36, Section A36.2(d), with the modifications discussed in this section. Data processing procedures may utilize either analog or digital techniques.

6.1 Missing Spectrum Level Information

The processing of recorded noise data often results in one-third octave band spectra with one or more "missing" band levels. This occurs most frequently at the higher frequencies. The missing noise information can result in errors in calculating values of PNL, PNLT, A-levels, EPNL, etc.

Based on the investigation summarized in Appendix C, we recommend that noise spectra be handled in the following manner:

a. Do not calculate or report PNL, PNLT, A-levels or other measures for spectra where less than 10 one-third octave frequency band levels are measured.

b. Where more than 10 band levels were measured, supply missing band levels as follows:

   (1) For missing high frequency band levels, generate values by extrapolating the slope of the two preceeding (lower) bands, provided the change in slope is 6 dB per third octave frequency band or greater. If the slope is less than 6 dB, assume a decrease of 6 dB per one-third octave frequency band.

   (2) For missing middle frequency bands, generate missing band levels by linear interpolation between the nearest adjacent band levels.

(3) For missing low frequency band levels, assume levels that are equal to the nearest measured band level.

c. On time history plots or noise level tabulations, identify, by some easily recognizable symbol, the cases where spectra having less than 20 band levels were measured.

6.2 <u>Flyover Sampling Intervals and Integration Times</u>

For flyover noise signals having durations of the order of 10 seconds or greater, a sampling interval of 0.5 second, and a signal integration time of 0.5 second, is generally entirely adequate for measuring the noise signal with little distortion. However, for shorter duration flyovers, particularly those having durations of less than 5 seconds, errors and distortions may be introduced by the relatively long 0.5 second sampling interval and integration time. A long sampling interval introduces increased probability for error in sampling the noise signal at the time of maximum level. This error may, in turn, introduce errors in measured spectrum levels and the selection of the angle of maximum radiation. The long integration time results in an underestimate of maximum noise levels, but introduces relatively little error in time-integrated measures such as EPNL and SEL.

Appendix C discusses these errors in more detail and presents examples of such errors based on analysis of several flyover noise signals.

To reduce the magnitude of errors in measuring maximum noise levels, the following sampling intervals and signal integration times should be used in processing flyover noise data.

Duration, in seconds	Sampling Interval and Integration Time, in seconds
$d \geq 5$	0.5
$5 > d > 2$	0.25
$d \leq 2$	0.125

The duration curves given in Figure C-1 may be used as a guide in estimating durations and in selecting sampling intervals and duration times in data processing.

7. CONVENTIONAL AIRCRAFT GROUND RUN-UP NOISE MEASUREMENTS

Noise measurements to define PNLT values for static engine operations should be obtained at the engine thrust settings typically employed in engine checkout and maintenance operations and should include operations at nominal takeoff thrust. Noise should be measured at positions along a circular arc about the aircraft with the arc having a radius of either 150 feet or 250 feet. Choice of the radius is dependent upon the physical size of the aircraft, distance between engines in multi-engine aircraft and the noise output of the aircraft.

In most cases the aircraft may be assumed to be symmetric about its longitudinal axis; hence measurements usually need be taken only on one side of the aircraft along a semi-circular path from 0° to 180° (with 0° taken as the forward end of the aircraft). For multi-engine aircraft, the origin of the semi-circle may be taken as a point on the longitudinal axis of the aircraft at the mid-point of a line connecting the exhausts of the inboard engines.

The noise should be measured at angles not more than 15° apart. At each position, noise levels should be recorded for a period of at least [illegible] seconds.

Engine operation should be stabilized prior to starting the noise measurements. Engine measurements should be maintained throughout the period of measurements, and significant fluctuations or changes noted.

7.[illegible] Aircraft Information

The engine information to be observed and reported may vary with type of engine and available instrumentation. Prior to each test, a review of available flight manuals and engineering data should be undertaken to determine the procedures for utilizing and correcting cockpit instrumentation to estimate the net thrust (in case of a turbojet engine) or shaft horse power (in case of turboprop aircraft) with appropriate engine or shaft RPM information. For a straight turbojet engine, the needed information will typically include: ambient air temperature, engine RPM, engine exhaust pressure ratio, engine exhaust gas temperature, and engine fuel flow. For fan engine, fan speed should be noted.

7.2 Noise Data Tabulation

The following data are to be obtained and tabulated for each position for each run:*

a. $PNLT_f$, PNL_f, AL_f, ALT_f.

b. One-third octave-band noise spectrum.

c. Surface temperature and relative humidity.

8. HELICOPTER FLYOVER MEASUREMENTS

Helicopter noise tests are planned so that all needed noise information for predicting noise levels for normal flight operations can be obtained from a set of controlled level flyovers (discussed in this section) and from sets of ground and hover measurements (see Section 9). Supplemental noise level measurements during actual approach and takeoff operations may be added to the test program but are not felt to be essential.

Level flight noise data are to be acquired over a range of engine power conditions. Flights are to be conducted at two altitudes -- 200 feet AGL and 400 feet AGL or 400 feet and 800 feet AGL. Two runs are to be made at each test condition, with runs to be in alternate (180 degrees) direction.

Helicopter altitudes and flight speeds should be selected so that the duration of the flyover signal is in excess of five seconds. Figure C-1 of Appendix C provides estimates of signal durations for fixed wing aircraft which may be helpful in initial flight planning.

The helicopter should fly directly over two ground microphone positions, located approximately 1000 feet apart. In addition to the two microphone positions directly underneath the flight path, microphones should be placed on either side of the centerline at a distance of 300 feet. The helicopter is to maintain a constant heading and constant altitude over the two microphone positions and for distances of 1.0 n miles both preceeding and following passage over the microphones.

The tests should be conducted at constant engine power, altitude and air speed. The flight should be conducted at airspeeds approximating those encountered at appropriate takeoff, landing and cruise operations. Selection of flight conditions should be governed by consideration of the helicopter operations likely to be employed within 15 to 20 miles of the air base.

Test conditions should cover the range of flight conditions typically encountered, with overlap, if necessary, to permit extrapolation to cover hot day conditions, or takeoffs and landings at 5000 feet pressure altitude. For most helicopters, tests at representative cruise speed and power should be included.

8.1 Aircraft Information

Section 5.1 is applicable, with the addition of rotor RPM information.

8.2 Radio Communications

See Section 5.2.

8.3 Time Synchronization

See Section 5.3.

8.4 Height Determination

See Section 5.4.

8.5 Repeat of Flights

See Section 5.5.

8.6 Noise Data Tabulation

See Section 5.6.

9. HELICOPTER HOVER AND GROUND MEASUREMENTS

Noise measurements to define AL, PNL or other noise measure values for ground operations should be obtained at engine power settings typically employed at engine check-up and maintenance operations, and ground idle conditions. Hover measurements include measurements with the helicopter hovering in-and-out of ground effect.

For the hover and ground measurements, the noise should be measured along a circular arc having a radius of either 150 feet or 250 feet. Choice of the radius is dependent upon the physical size and the noise output of the helicopter.

In most cases, the helicopter noise characteristics will not be symmetric about its longitudal axis; hence measurements should be taken along an entire 360° arc around the aircraft. Preferably, noise should be recorded on magnetic tape continuously, as the microphone is slowly moved around the helicopter (with suitable time synchronization provided to permit correlation of angular positions with the noise data). Angular positions for one-third octave band spectrum analysis can be selected by inspecting graphic level traces of the recorded noise signals passed through an A- or D-weighting network. One-third octave band spectrum should be measured at angles not more than 30° apart.

Alternatively, noise may be measured at fixed angles from 0° to 360° at angular intervals not more than 15° apart. At each position noise levels should be recorded for a period of at least 5 seconds.

Engine and aircraft conditions should be stabilized prior to the noise measurements. Engine measurements should be maintained throughout the period of noise measurements, and significant fluctuations noted.

For hover measurements, in ground effect, the aircraft should be at a stabilized condition, at a height between 0 to 5 feet above ground. For hover, out of ground effect, the hover altitude should be approximately equal to one rotor diameter.

9.1 Aircraft Information

Section 7.1 is applicable with the addition of rotor RPM data.

9.2 Noise Data Tabulation

See Section 7.2.

10. COMPUTATION OF EPNL VERSUS DISTANCE CURVES FROM LEVEL FLYOVER NOISE MEASUREMENTS

It is assumed that EPNL is the sum of PNLTM + D, and that, for a given aircraft condition, the EPNL varies with distance due to:

a. Changes in PNLT due to inverse square changes in SPL's and changes in SPL's due to air absorption.

b. Changes in D which are directly proportional to air speed and inversely proportional to distance.

It is further assumed that PNLTM is generated by the aircraft at a maximum directivity angle, θ. Therefore, if the EPNL is known at a given distance, air speed, engine power setting and maximum directivity angle, it can be computed at any other distance.

To reduce the possibility of significantly underestimating noise levels at large distances, the maximum directivity angle, θ, and corresponding noise spectra is chosen on the basis of PNLM, rather than PNLTM. Appendix E discusses, in some detail, the reasons for this choice, and provides some examples of errors incurred by use of PNLTM rather than PNLM as the criteria for choosing θ.

Appendices F and G outline the derivation of equations for directivity angle and slant distance utilized in this section.

All sub-sections, except 10.7, assume air-to-ground propagation. Sub-section 10.7 is concerned with computation of noise levels for ground-to-ground propagation.

10.1 Computation of SEL and SELT Versus Distance Curves

In a manner parallel to the calculation of EPNL, SEL and SELT values can also be calculated for any distance. For such calculations it is assumed that SELT is the sum of the A-level maximum (ALM) plus a duration correction D(AL). Similarily, it is assumed that SELT is the sum of the tone-corrected A-level maximum (ALTM) plus a duration correction, D(ALT). It is further assumed that SEL and SELT vary with distance due to:

a. Changes in ALM and ALTM which are due to inverse square changes in SPL's and changes in SPL's due to air absorption.

b. Changes in D(AL) and D(ALT) which are directly proportional to air speed and inversely proportional to distance.

It is also assumed that ALM and ALTM are generated at an angle of maximum radiation, θ. As in the calculation of EPNL, θ is chosen on the basis of PNLM. As discussed in Appendix E, there will generally be little or no error introduced by use of PNLM, rather than ALM or ALTM, as a basis for choosing θ.

10.2 Normalization of Level Flyover Data to Standard Day Conditions

Develop basic description of noise levels as a function of engine performance from level flyovers. Normalize all flyover data to 1000 feet distance, reference acoustical day conditions. Data for low engine powers should be normalized to approach speed, high power data, to climbout speed. Utilize the following steps, referring to Figure 1 for geometry. In the notation, "J" indicates the "J-th" flight for a specified power setting; "f" indicates measured noise data for which only record/playback system corrections have been applied.

a. List test height above ground, h_J (ft)

b. List time interval, Δt_J (sec)

c. List true airspeed, V_J (kt)

d. Obtain $v_J = 1.69\ V_J$ (ft/sec)

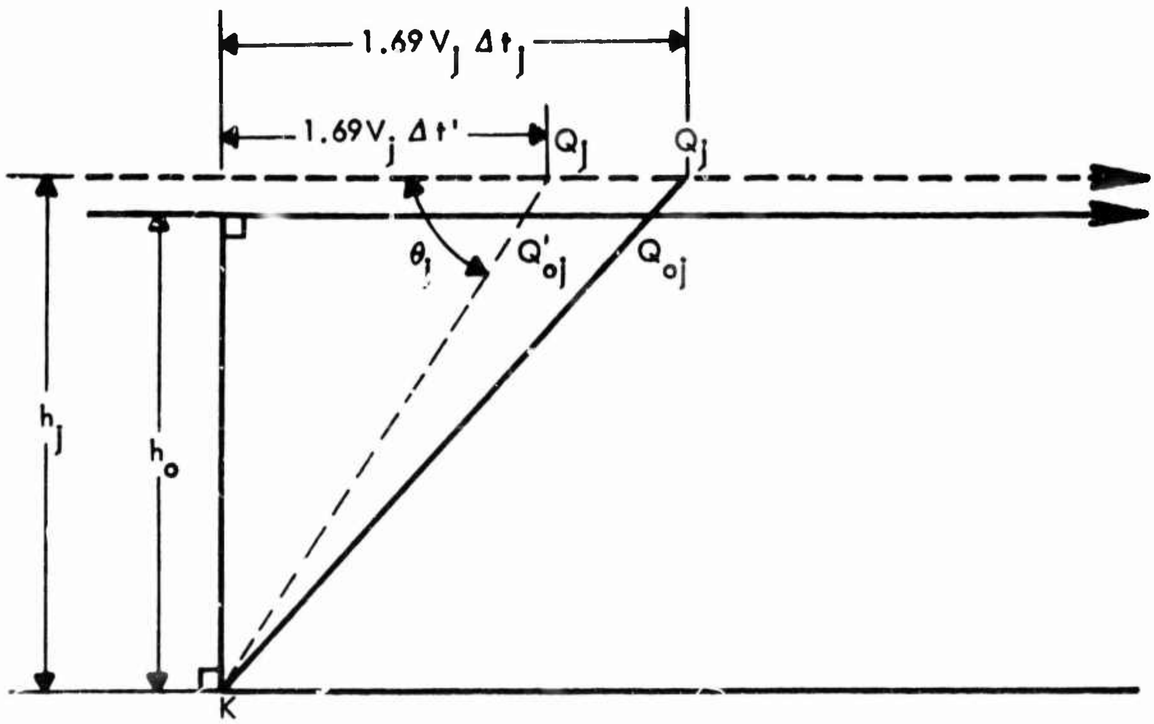


FIGURE 1. LEVEL FLYOVER GLOMETRY

e. Obtain $\sin \theta_j = \dfrac{h_j\left(1-\dfrac{v_j^2}{c^2}\right)}{\left[h_j^2\left(1-\dfrac{v_j^2}{c^2}\right)+(v_j\Delta t)^2\right]^{1/2}-\dfrac{v_j^2\Delta t}{c}}$

f. Obtain slant distance $KQ_j' = \dfrac{h_j}{\sin \theta_j}$ (ft)

g. Obtain $KQ_{oj}' = \dfrac{h_o}{\sin \theta_j}$ (ft)

h. Compute $\alpha_i KQ_j'$ for all i (ft)

i. Compute $\alpha_{ir}\ KQ_{oj}'$ for all i (where α_{ir} refers to sound attenuation coefficients for 59° F, 70% relative humidity). (ft)

j. Obtain $\Delta_{5j} = 20 \log_{10} \dfrac{KQ'_j}{KQ'_{oj}}$ (dB)

k. Obtain $\Delta_{6j} = PWL_{ref} - PWL_j$

where Δ_6 is the difference between the aircraft sound power level at reference thrust conditions and at the field thrust conditions. See Appendix I for an outline of one method for determining Δ_6.

l. Calculate Δ_{7j} where

$$\Delta_{7j} = 10 \log \frac{\rho_j}{\rho_o} \sqrt{\frac{T_j+273}{T_o+273}} = 10 \log \frac{P_j}{P_o} \sqrt{\frac{T_o+273}{T_j+273}}$$

where

T_j = surface temperature in °C during field measurements

T_o = surface temperature (15°C) for standard day

ρ_j = air density during field measurements

ρ_o = air density for standard day

P_j = surface barometric pressure during field measurements

P_o = surface barometric pressure for standard day.

Note that Δ_{7j} is an adjustment for the variation of the acoustic characteristic impedance (ρc) during the measurements from the characteristic air impedance for a standard day at sea level.

m. Obtain and list:

$$SPL'_{ij} = SPL(\Theta)_{ij} + \alpha_i \, KQ'_j - \alpha_{ir} \, KQ'_{oj} + \Delta_{5j} + \Delta_{6j} - \Delta_{7j}$$

(where SPL $(\Theta)_{ij}$ is the one-third octave band SPL for $PNLM_j$). (dB)

n. Compute AL'_j, ALT'_j, PNL'_j, and $PNLT'_j$ from SPL'_{ij}.

(Note that $ALT'_j = AL'_j + C'_j$ and $PNLT'_j = PNL'_j + C'_j$)

o. Obtain

$$\Delta_{8j} = PNLT'_j - PNLT\ (\Theta)_j \qquad \text{(PNdB)}$$

$$\Delta_{9j} = AL'_j - AL(\Theta)_j \qquad \text{(dB)}$$

$$\Delta_{10j} = ALT'_j - ALT(\Theta)_j \qquad \text{(dB)}$$

(or, $\Delta_{10j} = \Delta_{9j} + C'_j - C(\Theta)_j$)

p. Obtain $\Delta_{2j} = -10 \left[\log_{10} \dfrac{KQ'_j}{KQ'_{oj}} - \log_{10} \dfrac{V_j}{V_{ref}} \right]$ (dB)

q. List SEL_{fj}, $SELT_{fj}$ and $EPNL_{fj}$

r. Obtain $SEL_j = SEL_{fj} + \Delta_{9j} + \Delta_{2j}$ (dB)

$SELT_j = SELT_{fj} + \Delta_{10j} = \Delta_{2j}$ (dB)

$EPNL_j = EPNL_{fj} + \Delta_{8j} + \Delta_{2j}$ (EPNdB)

s. Compute the average values and standard deviations for the following quantities for a specified power setting airspeed:

$\overline{SEL}$ and s_{SEL}	(dB)
$\overline{SELT}$ and s_{SELT}	(dB)
$\overline{EPNL}$ and s_{EPNL}	(EPNdB)
$\overline{SPL}_i'$ and $s_{SPL_i'}$	(dB)

where i designates the individual one-third octave bands.

t. Compute $\overline{AL}$, $\overline{ALT}$, $\overline{PNL}$ and $\overline{PNLT}$ from $\overline{SPL}_i$

u. Obtain Θ_j from $\sin^{-1}(\sin \Theta_j)$.

v. Compute the average value and standard deviation for the directivity angle, Θ_j, for a specified power setting and airspeed:

$\overline{\Theta}$ and s_Θ

In Step s the 90% confidence intervals implied by the standard deviations may be estimated from Figure 2.

Noise measurements at positions to one side of the flight track may be used to supplement overhead measurements by replacing h_j in the above expressions with $s_j = (h_j^2 + d^2)^{1/2}$. Sideline data should only be used for this purpose if h_j and d are selected such that h_j/d is greater than 0.15.

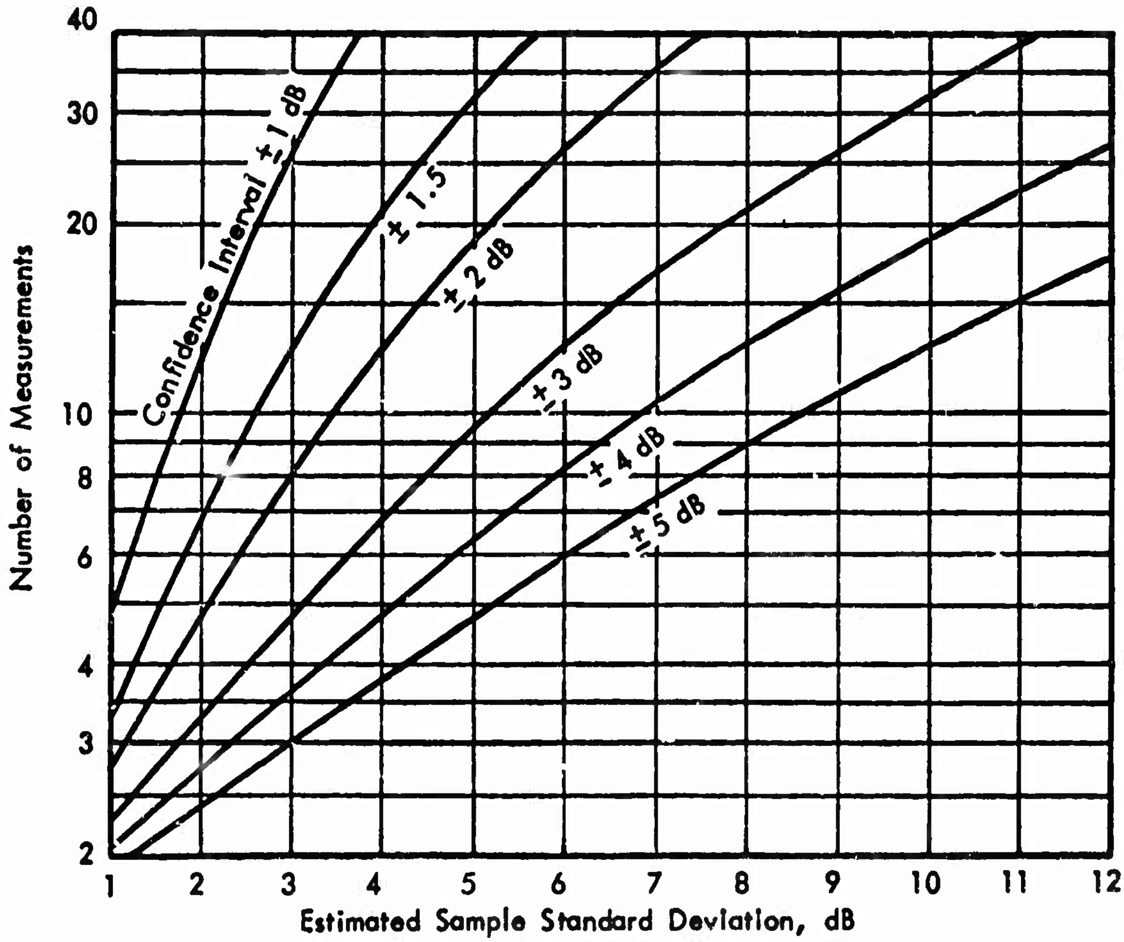


FIGURE 2. NUMBER OF MEASUREMENTS NEEDED TO ASSURE A 90 PER CENT CONFIDENCE INTERVAL

10.3 Adjustment of EPNL, SEL or SELT to Any Slant Distance At Reference Conditions

Refer to Figure 3 for geometry. The EPNL at any point, L, on the ground, perpendicular to the ground projection of the flight path, is given by:

$$EPNL_x = EPNL_{h_o} + PNLT_x - PNLT\,(\theta)_{h_o} + \Delta_{2x}$$

where:

$$\Delta_{2x} = 10\left[\log_{10}\frac{LX\sin\theta}{h_o}\right]$$

$$LX = \left[\frac{h_1^2\cos\gamma + d^2}{\sin^2\theta}\right]^{1/2} = \left[\frac{h_o^2 + d^2}{\sin^2\theta}\right]^{1/2}$$

$$h_o = h_1\cos\gamma$$

In a similar manner, SEL and SELT at any point, L, on the ground perpendicular to the ground projection of the flight path are given by:

$$SEL_x = SEL_{h_o} + AL_x - AL(0)_{h_o} + \Delta_{2x}$$

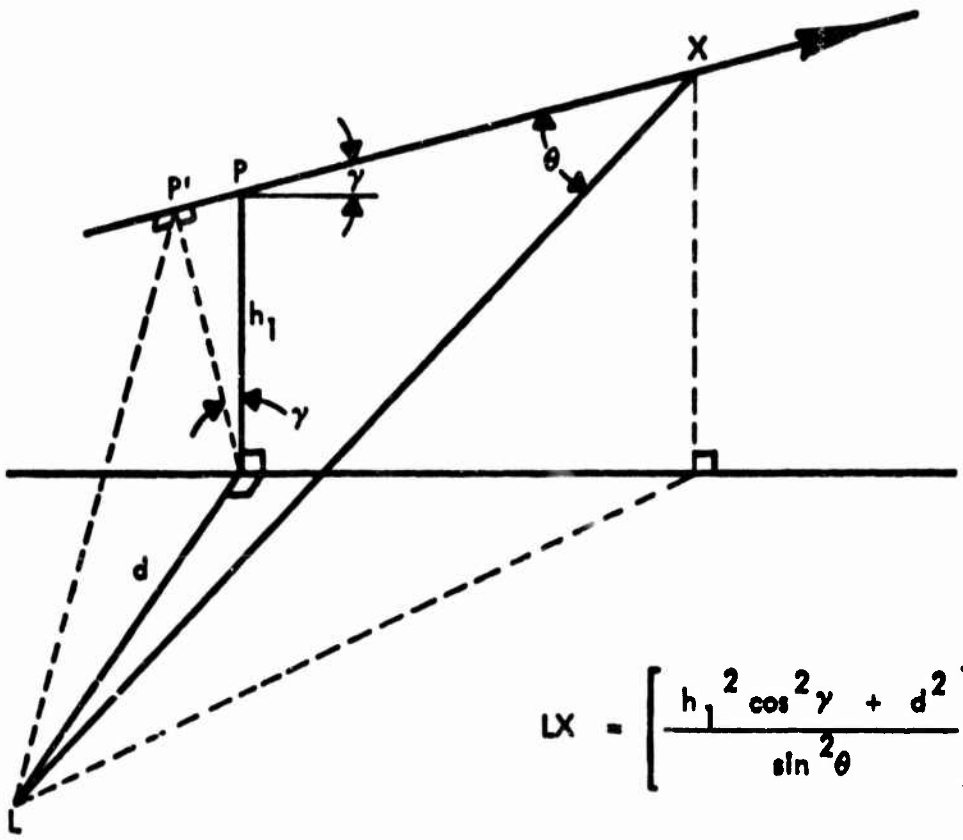
and

$$SELT_x = SELT_{h_o} + ALT_x - ALT(0)_{h_o} + \Delta_{2x}$$

$PNLT_x$, AL_x and ALT_x are obtained from the one-third octave SPL spectrum, SPL_{1x}, where individual one-third octave band levels are computed as follows:

$$SPL_{1x} = SPL_{1h_o} - \alpha_{1r}\left(LX - \frac{h_o}{\sin\theta}\right) - 20\log_{10}\frac{LX\sin\theta}{h_o}$$

and SPL_{1h_o} are the one-third octave band levels from which $PNLT(0)_{h_o}$, $AL(0)_{h_o}$ and $ALT(0)_{h_o}$ are computed.



$$LX = \left[\frac{h_1^{\,2}\cos^2\gamma + d^2}{\sin^2\theta}\right]^{\frac{1}{2}}$$

FIGURE 3. GEOMETRY FOR EPNL AT A POINT ON THE GROUND

10.4 Calculation of Averaged Level Flight EPNL, SEL and SELT at Any Slant Distance At Reference Conditions

For the averaged level flight data obtained under Section 10.2, compute EPNL, SEL and SELT values at various distances in accord with the following steps:

a. Compute SPL_{ix} at the slant distance S_x:

$$SPL_{ix} = \overline{SPL}_i - \alpha_{ir}\left(\frac{S_x - h_o}{\sin\,\bar{\theta}}\right) - 20\log\frac{S_x}{h_o} \qquad \text{(dB)}$$

b. Compute $PNLT_x$, PNL_x, AL_x and ALT_x from SPL_{ix}. (PNdB,dB)

c. Compute $\Delta_{2x} = 10\left[\log_{10}\frac{S_x}{h_o}\right]$ (dB)

d. Obtain $EPNL_x$ where

$$EPNL_x = \overline{EPNL} + PNLT_x - \overline{PNLT} + \Delta_{2x} \qquad \text{(EPNdB)}$$

$$SEL_x = \overline{SEL} + AL_x - \overline{AL} + \Delta_{2x} \qquad \text{(dB)}$$

$$SELT_x = \overline{SELT} + ALT_x - \overline{ALT} + \Delta_{2x} \qquad \text{(dB)}$$

10.5 Adjustment of SELT, SEL, and EPNL at Reference Conditions to Other Speed, Weather or Engine Power Conditions

For relatively small changes from reference speed, weather or engine power conditions (changes of the order of 5 dB or less), adjusted SELT, SEL or EPNL quantities may be obtained from the quantities at reference conditions at the same slant distance S_x, obtained from either Section 10.3 or 10.4, by the following expressions:

$$SELT'_y = SELT_x - 10 \log \frac{V_y}{V_{ref}} - \Delta_{6y} + \Delta_{7y} \qquad \text{(dB)}$$

$$SEL'_y = SEL_x - 10 \log \frac{V_y}{V_{ref}} - \Delta_{6y} + \Delta_{7y} \qquad \text{(dB)}$$

$$EPNL'_y = EPNL_y - 10 \log \frac{V_y}{V_{ref}} - \Delta_{6y} + \Delta_{7y} \qquad \text{(EPNdB)}$$

where

$\text{——}'_y$ denotes the noise level at slant distance S_x under new conditions y, and ——_x, the noise levels at S_x under reference conditions.

$$\Delta_{6y} = PWL_{ref} - PWL_y \qquad \text{(dB)}$$

where

Δ_{6y} is the difference between the aircraft sound power level at the reference thrust conditions and at the desired thrust condition. Appendix I outlines one method for determining Δ_{6y}.

and $$\Delta_{7y} = 10 \log \frac{\rho_y}{\rho_{ref}} \sqrt{\frac{T_y + 273}{T_{ref} + 273}} \qquad \text{(dB)}$$

or $$\Delta_{7y} = 10 \log \frac{P_y}{P_{ref}} \sqrt{\frac{T_{ref} + 273}{T_y + 273}} \qquad \text{(dB)}$$

10.6 Calculation of Smoothed PNLT, EPNL, ALT, SELT Values At Any Slant Distance

Graphs of tone-corrected noise levels versus distance, using values computed in accordance with Section 10.4, may show occasional irregularities at one or more distances due to tone-corrected adjustments that may reflect false (pseudo) tones. This section provides for the calculation of smoothed noise level versus distance data that will not contain such irregularities.

The basis for the procedure outlined in this section lies in the following two assumptions which are based upon inspection of noise level versus distance data for a number of military and civil aircraft:

(a) The tone correction values typically do not vary much in magnitude for noise spectra calculated at distances ranging from 200 ft. to about 3,000 ft.

(b) At very large distances (10,000 ft. or greater) any tone adjustment should be negligible.

The smoothing steps outlined below assume computation of noise level values in accordance with Section 10.4.

(a) Determine the tone corrections at the reference distance, h_o

$$c_o = PNLT - PNL$$

$$= ALT - AL$$

$$c_o' = SELT - SEL$$

(b) For distances, x, from 200 to 3500 ft., set

$$PNLT_x = PNL_x + c_o$$

$$ALT_x = AL_x + c_o$$

$$EPNL_x = EPNL_{h_o} + PNL_x - PNL_{h_o} + c_o' + \Delta_{2x}$$

$$SELT_x = SEL_x + c_o'$$

(c) For distances greater than 3500 ft., use expressions as in (b) above, but with the following values for c_o and c_o':

distance, x	$c_o(x)$	$c_o'(x)$
4,000 ft.	0.8 c_o	0.8 c_o'
5,000 ft.	0.6 c_o	0.6 c_o'
6,300 ft.	0.4 c_o	0.4 c_o'
8,000 ft.	0.2 c_o	0.2 c_o'
10,000 ft. and greater	0	0

10.7 Calculation of Noise Data Obtained from Flight Measurements for Ground-to-Ground Sound Propagation

As discussed in Appendix J, aircraft noise levels measured at the sideline during aircraft takeoffs, or at very small grazing angle during aircraft in flight, show significantly lower noise levels than would be estimated using the air-to-ground propagation procedures of the previous sub-sections. This sub-section develops noise levels for ground-to-ground propagation to provide a conservative estimate of sideline noise levels or noise levels observed at low grazing incidence. The procedure follows that of Section 10.4 with the addition of an excess ground attenuation term that is a function of frequency and distance from the aircraft, and a separate adjustment Δ_g. This adjustment, Δ_g, allows for the typical sideline attenuation provided by intervening obstacles (typically, buildings,terrain, or trees and shrubs). The procedures are applicable to data obtained from flight tests and which has been adjusted to standard day conditions according to Section 10.2.

For the averaged level flight data obtained under Section 10.2, compute EPNL, SEL and SELT values at various distances as follows:

(a) Compute SPL_{ix} at the slant distance S_x:

$$SPL_{ix} = \overline{SPL}_i - \alpha_{ir}\left(\frac{S_x - h_o}{\sin\ \bar{\theta}}\right) - 20 \log \frac{S_x}{h_o}$$

$$- \varepsilon_i\ (x) - \Delta_g \qquad \text{(dB)}$$

where: ε_i (x) is the excess ground attenuation in the "i-th" frequency band at distance x as obtained from Figure 4, and Δ_g is a ground loss factor, taken as 5 dB.

(b) Compute $PNLT_x$, PNL_x, AL_x and ALT_x from SPL_{ix}. (PNdB, dB)

(c) Compute $\Delta_{2x} = 10 \left[\log_{10} \frac{S_x}{h_o}\right]$ (dB)

(d) Obtain $EPNL_x$ where

$$EPNL_x = \overline{EPNL} + PNLT_x - \overline{PNLT} + \Delta_{2x} \qquad \text{(EPNdB)}$$

$$SEL_x = \overline{SEL} + AL_x - \overline{AL} + \Delta_{2x} \qquad \text{(dB)}$$

$$SELT_x = \overline{SELT} + ALT_x - \overline{ALT} + \Delta_{2x} \qquad \text{(dB)}$$

Apply procedure of Section 10.6 to smooth irregularities present in the tone corrected measures.

11. COMPUTATION OF PNLTM VERSUS DISTANCE CURVES FROM GROUND RUN-UP OR HOVER NOISE MEASUREMENTS

From noise spectra measured along a 250 foot arc and corrected to standard day conditions, noise spectra are estimated at other distances, applying inverse square corrections, and corrections for air absorption and for excess ground attentuation. No spectrum adjustments are made for ground reflection effects. Appendix H reviews the reasons for currently omitting ground reflection adjustments.

11.1 Basic Noise Description at 250 Feet

Develop basic descriptions of noise levels as a function of engine performance from ground run-up or hover operations. Normalize all data to obtain polar plots of PNLT and ALT at a radius of 250 feet from the aircraft for reference acoustical conditions. In the following description "ϕ" indicates the polar angle in a horizontal plane parallel to the ground, measured from the forward direction of the aircraft and "f" indicates measured noise data for which only microphone/record/playback systems corrections have been applied.

a. Determine $\alpha_1 x - \alpha_{1r}\, 250$, where x is the radius of the field measurements. (dB)

b. Determine Δ_7 where

$$\Delta_7 = 10 \log \frac{\rho_f}{\rho_{ref}} \sqrt{\frac{T_f + 273}{T_{ref} + 273}} \qquad \text{(dB)}$$

or

$$\Delta_7 = 10 \log \frac{P_f}{P_{ref}} \sqrt{\frac{T_{ref} + 273}{T_f + 273}} \qquad \text{(dB)}$$

c. Obtain $\Delta_6 = PWL_{ref} - PWL_f$, where Δ_6 is the difference between the aircraft sound power level of reference thrust conditions and at the observed field thrust conditions. Appendix I describes one method for determining Δ_6. (dB)

d. Obtain $SPLC(\phi, 250)_{io}$ where

$$SPL(\phi, 250)_{io} = SPL(\phi)_i + 20 \log \frac{x}{250} + \alpha_i\, x - \alpha_{ir} \cdot 250 + \Delta_6 - \Delta_7 \quad \text{(dB)}$$

e. Compute $ALT(\phi)_o$, $AL(\phi)_o$ and $PNLT(\phi)_o$ from $SPL(\phi, 250)_{io}$ (dB,PNdB)

11.2 Calculation of ALT(ϕ), AL(ϕ) and PNLT(ϕ) at Any Distance at Reference Conditions

The ALT, AL and PNL at any angle ϕ and any distance x greater than 250 feet is computed from $SPL(\phi, 250)_{io}$ by:

$$SPL(\phi,x)_i = SPL(\phi)_{io} - 20 \log_{10} x - \alpha_{io}(x-250) - \xi_i(x) + 48 \quad \text{(dB)}$$

where $\xi_i(x)$ is the excess ground attenuation in the "i-th" frequency band at distance x as obtained from Figure 4.

11.3 Adjustment of ALT, AL and PNL at Reference Conditions to Other Weather or Thrust Conditions

For relatively small changes from reference weather or thrust conditions (of the order of 5 dB or less), adjusted ALT, AL or PNLT quantities may be obtained from the quantities at reference conditions at the same angle (ϕ) and distance, x, by the following expressions:

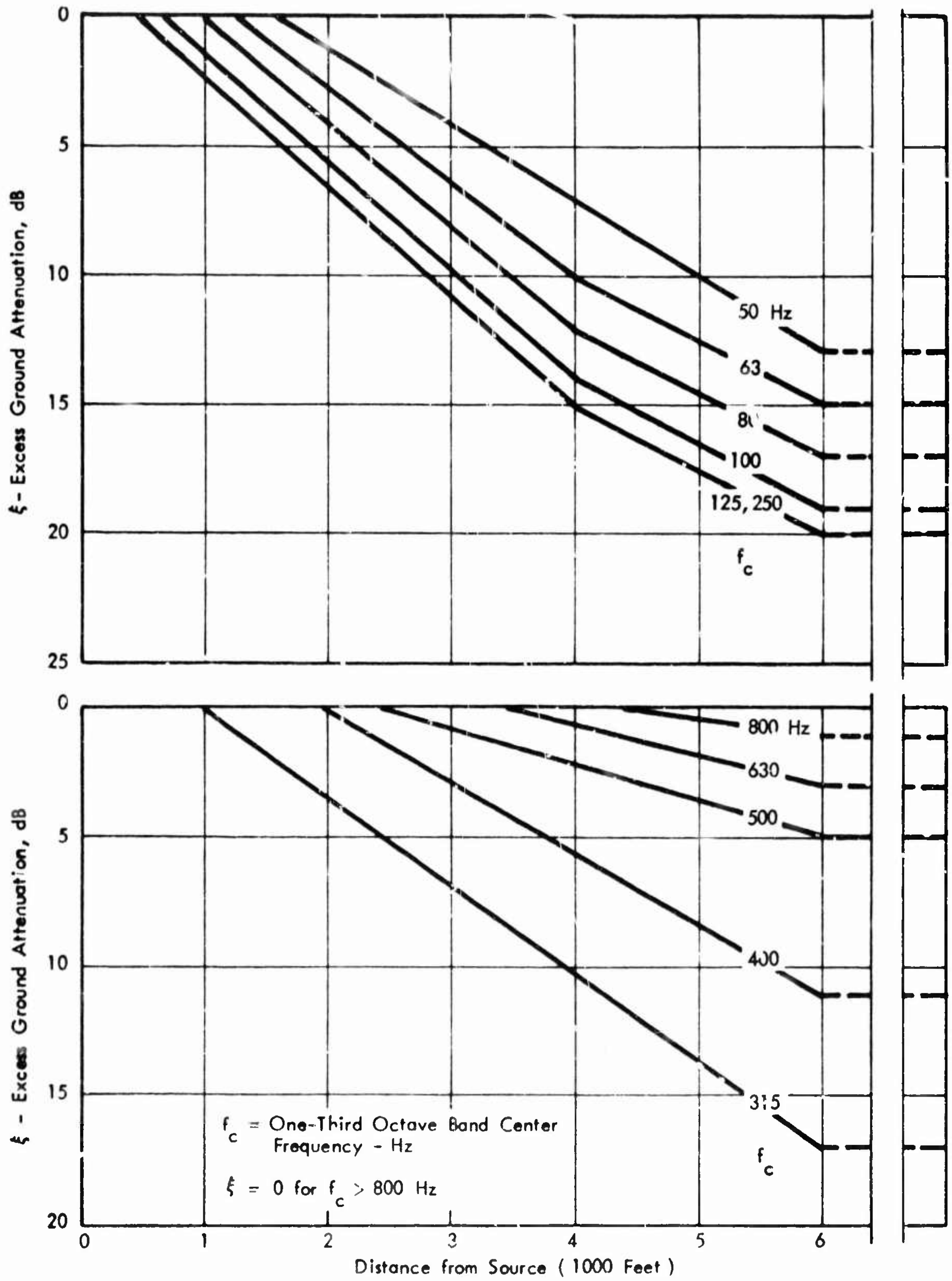


FIGURE 4. EXCESS GROUND ATTENUATION FOR GROUND-TO-GROUND SOUND PROPAGATION

$$\text{ALT}(\phi, x)_y = \text{ALT}(\phi, x) - \Delta_{6y} + \Delta_{7y} \qquad \text{(dB)}$$

where $\Delta_{6y} = \text{PWL}_{ref} - \text{PWL}_y$ (dB)

and

$$\Delta_{7y} = 10 \log \frac{\rho_y}{\rho_{ref}} \sqrt{\frac{T_y + 273}{T_{ref} + 273}} \qquad \text{(dB)}$$

or

$$= 10 \log \frac{P_y}{P_{ref}} \sqrt{\frac{T_{ref} + 273}{T_y + 273}} \qquad \text{(dB)}$$

Similarily,

$$\text{AL}(\phi, x)_y = \text{AL}(\phi, x) - \Delta_{6y} + \Delta_{7y} \qquad \text{(dB)}$$

$$\text{PNLT}(\phi, x)_y = \text{PNLT}(\phi, x) - \Delta_{6y} + \Delta_{7y} \qquad \text{(PNdB)}$$

11.4 Calculation of SELT, SEL and EPNL at any Distance and Angle

At any angle (ϕ), and distance x

$$\text{SELT}(\phi, x)_y = \text{ALT}(\phi, x)_y + 10 \log_{10} D \qquad \text{(dB)}$$

$$\text{SEL}(\phi, x)_y = \text{AL}(\phi, x)_y + 10 \log_{10} D \qquad \text{(dB)}$$

$$\text{EPNL}(\phi, x)_y = \text{PNLT}(\phi, x)_y + 10 \log_{10} D - 10 \qquad \text{(EPNdB}$$

where D is the duration in seconds.

11.5 Calculation of Smoothed PNLT or ALT Values at any Slant Distance

Graphs of tone-corrected noise levels versus distance using values computed in accordance with Section 11.2 may show occasional irregularities at one or more distances due to tone-corrected adjustments that may reflect false (pseudo) tones. This section provides for the calculation of smoothed noise level versus distance data that will not contain such irregularities.

(a) Determine the tone corrections at the reference distance of 250 feet.

$$c_o = \text{PNLT} - \text{PNL}$$
$$= \text{ALT} - \text{AL}$$

(b) For distances, x, from 200 to 3500 ft., set

$$\text{PNLT}\ (\phi,x) = \text{PNL}\ (\phi,x) + c_o\ (\phi)$$
$$\text{ALT}\ (\phi,x) = \text{AL}\ (\phi,x) + c_o\ (\phi)$$

(c) For distances greater than 3500 ft., use expressions as in (b) above, but with the following values for $c_o(\phi)$:

distance, x	$c_o(\phi,x)$
4,000 ft.	$0.8\ c_o(\phi)$
5,000 ft.	$0.6\ c_o(\phi)$
6,300 ft.	$0.4\ c_o(\phi)$
8,000 ft.	$0.2\ c_o(\phi)$
10,000 ft. and greater	0

12. AIRCRAFT PERFORMANCE INFORMATION

This section outlines the aircraft performance information needed for the development of aircraft profile and EPNL data to be used in NEF calculations.

The performance information requested is generally available directly from (or can be calculated from data contained within) the various application curves given in the Performance Section of the specified Aircraft Handbooks.

12.1 Specified Airport Conditions

Generally the information described under the following subsections (12.2 and 12.3) will be required for three airport conditions:

Airport Altitude	Temperature	Wind
Sea Level	59° F (Std. day)	0
Sea Level	100° F	0
5000 feet	41° F (Std. atmos)	0

12.2 Takeoff Information

Takeoff performance information will be needed for a distance/altitude range extending either to 12 nautical miles from start of takeoff roll, or 10,000 feet above the runway. This takeoff information, as described below, should be reported for maximum gross takeoff weight and for the typical minimum operating gross weight (this weight may be specified in terms of percent of maximum gross weight).

a. An altitude profile graph depicting the height of the aircraft above the runway as a function of distance from brake release. (The profile can begin at the "clear 50 foot obstacle" distance.) The profile should reflect typical mission procedures and may be segmented to reflect changes in power settings.

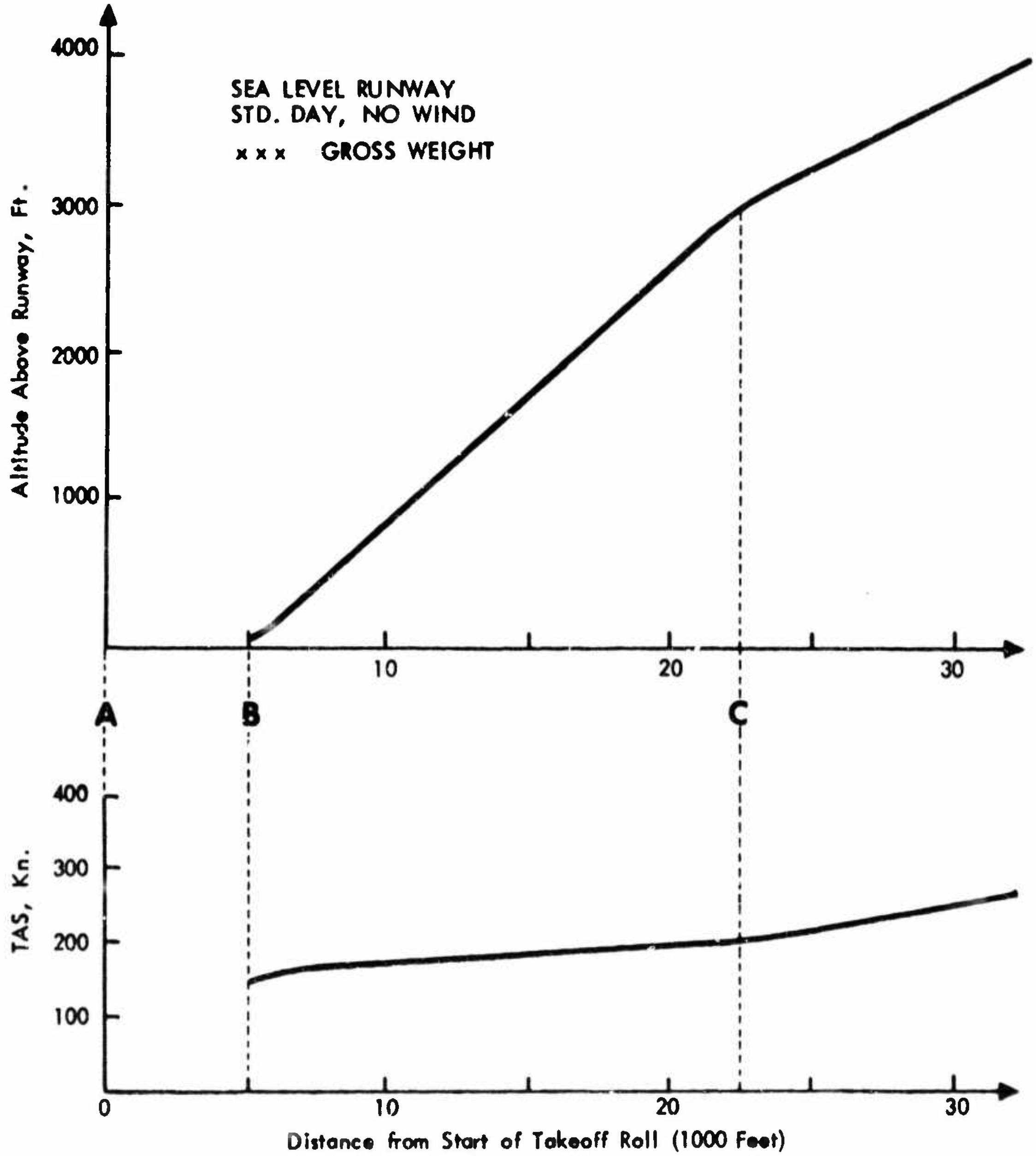
b. A true air speed profile to accompany the takeoff profile described in a above. This profile should provide the TAS, beginning at the "clear 50 foot obstacle" distance.

c. Appropriate information to determine approximate engine power settings (EPR, % rpm, etc) for each segment of the takeoff profile.

Figure 5 summarizes the performance information described above.

12.3 Landing Performance Information

A three degree landing profile will be assumed unless a different landing profile is normally used for the basic aircraft mission. Tables and/or graphs should provide the TAS and the engine power settings (EPR, % rpm, etc.) typically employed for landing at the maximum landing weight, and at a typical minimum operating landing weight.



REFERENCE POINT	AIRCRAFT	NET THRUST *
A	Start of Takeoff	x x x
B	Clear 50 Ft. Obstacle	x x x
C	Reduction to Climb Power	x x x Before } Power Reduction x x x After

* or related engine parameters

FIGURE 5. TYPICAL SUMMARY OF TAKEOFF PERFORMANCE DATA

REFERENCES

References 1 through 4 from a part of the test plan, when called out. References 5 through 9 are companion reports to this document, and were prepared as part of the same research program.

1. Federal Aviation Regulations, Part 36: "Noise Standards: Aircraft Type Certification", 1 December 1969 issue or later.

2. ISO Recommendation R507, "Procedure for Describing Aircraft Noise Around an Airport", second edition, June 1970 or later.

3. IEC Publication No. 179, "Precision Sound Level Meters", dated 1965 or later.

4. SAE ARP 866, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise", August 1964 or later revision.

5. Bishop, D. E., "Community Noise Exposure Resulting From Aircraft Operations: Application Guide for Predictive Procedure," AMRL TR-73-105, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

6. Galloway, W. J., "Community Noise Exposure Resulting From Aircraft Operations: Technical Review," AMRL TR-73-106, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

7. Reddingius, N. H., "Community Noise Exposure Resulting From Aircraft Operations: Computer Program Operator's Manual," AMRL TR-73-108, Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio.

8. Horonjeff, R. D., Kandukuri, R. R., and Reddingius, N. H., "Community Noise Exposure Resulting From Aircraft Operations: Computer Program Description," AMRL TR-73-109, Aerospace Medical Laboratory.

9. Speakman, J. D., Powell, R. G., and Cole, J. N., "Community Noise Exposure Resulting From Aircraft Operations: Acoustic Data on Military Aircraft," AMRL TR-73-110, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

APPENDIX A

TEST PROCEDURE RATIONALE

One of the basic premises in this test plan is that the noise produced at any point on the ground by an aircraft in flight is defined solely by the engine power setting, the slant distance to the aircraft, and the directivity pattern of the noise field described in ISO recommendation R507, "Procedure for Describing Aircraft Noise Around An Airport", second edition, June 1970. These procedures specify measurements of the noise produced during level flyovers of the aircraft at different power settings and at different heights. The measurement and analysis equipment and acoustical data analysis techniques are generally consistent with both R507 and FAR Part 36.

There are significant differences between the choice of measurement points and aircraft operating conditions between FAR Part 36 and this test plan. Part 36 is concerned only with the EPNL value obtained at three fixed locations, 3.5 n mile from brake release on takeoff, 1.0 n mile from runway threshold on approach, and the maximum sideline EPNL at 0.25 or 0.35 n mile, depending upon aircraft size. Further, these values are obtained only for engine power settings at maximum gross takeoff and landing weights.

To compute EPNL at any distance for a full range of operating weights and procedures, it is necessary to know considerably more about the aircraft as a noise source. In fact, even to comply with the adjustments of Part 36 test data to reference day conditions it is necessary to know more about the aircraft than is specifically identified in Part 36.

The basic technique for adjusting acoustical measurement data for certification purposes to reference day conditions utilizes level flyover data at various engine power settings to define the aircraft as a noise source. This technique has been used by the authors to adjust Part 36 test data to reference day conditions, over a wide range of test conditions, in a number of separate certification programs approved by FAA. Under a proposed change* in Part 36, this approach is specified in lieu of different procedures now schematically indicated in the regulation. In its comment on the proposed change, Docket No. 11412, Notice 71-26, the Aerospace Industries Association notes that in all of its certification efforts, the level flyover technique has been used.

The accuracy of predicting takeoff or approach noise to slant distances of up to 4000 feet from level flyover data at 500 feet have been examined for three aircraft, the Gulfstream II, the Sabreliner, and the Jet Commander. Agreement of approach noise levels calculated from level flyovers, with actual approach noise levels is within a few tenths of decibels. Takeoff comparisons range from 0.1 to about one decibel for these cases. This is of the same magnitude as the standard deviation of the measurements, which varied from 0.7 to 1.3 dB.

An alternate approach to the procedure described herein is to make many more measurements at a number of positions under the takeoff and approach path of the aircraft at various power settings and gross weights. Acquisition of an adequate set of data on this basis would require from three to four times the number of micropnone positions and on the order of twice the test flight hours with no improvement in acoustical accuracy. Further, radar or photo-theodolite flight path tracking would be essential in such a program; in this test plan it may be helpful, but is not

*FAA Notice of Proposed Rule Making, Noise Type Certification and Acoustical Change Approvals, FAA Docket 11412, Notice 71-26.

essential. This point is highly significant in determining the suitability of test sites since only a few tracking facilities are available in this country.

In summary, the test plan specified obtains the required data with the desired accuracy, a minimum of data acquisition and test flight time, and provides wide flexibility in test sites.

APPENDIX B

FLYOVER NOISE MEASUREMENTS AT LARGE DISTANCES

In applying NEF procedures, one may wish to estimate EPNL values over distances ranging from several hundred feet to tens of thousands of feet (20,000 feet or beyond) depending on volume of operations and other factors. The procedures outlined in this test plan predict EPNL values from measurements made at moderate slant distances (order of 400 feet to 1000 feet), and do not utilize measurements at much larger distances from the aircraft, on a routine basis.

While the estimation procedures outlined in this test plan do involve errors due to basic assumptions (primarily in estimating D, the duration correction, and in applying atmospheric absorption coefficients) it is believed that these errors would not be substantially reduced by introducing measurements at large distances, or aircraft flights at higher altitudes. While further experimental test programs involving measurements at small and large slant distances are extremely desirable, current data indicate that measurements at large distances often show relatively large scatter and are subject to uncertainties in interpretation which greatly detract from their usefulness. Errors and uncertainties arise from several factors, including the following:

1. Correlation of engine noise output between flights at high altitudes and those at low altitudes is often inexact because of uncertainties of the effects of altitude and speed on engine source output and directivity.

2. Propagation over long path distances is subject to fluctuations and errors introduced by atmospheric path variables. Current understanding of the effect of different atmospheric variables on

the propagation of aircraft signals is incomplete, and test and analysis procedures to account for atmospheric effects are not well established.

3. Measurements at large distances yields relatively low level signals, with portions of the spectra (particularly higher frequency bands) obscured by ambient noise levels. Thus, incomplete spectral information is obtained. In addition, methods of correcting for the effects of the background noise may introduce sizable errors or uncertainties in defining the aircraft noise levels.

APPENDIX C

CONSIDERATIONS IN SELECTING FLIGHT ALTITUDES AND DATA SAMPLING INTERVALS FOR FLYOVER NOISE MEASUREMENTS

A. INTRODUCTION

The noise processing techniques defined under FAA FAR 36 for handling flyover data were developed in the context of flyover signals that would typically have durations (as measured 10 dB down from the maximum value) of the order of 10 seconds or greater. For signals of this duration, sampling intervals of 0.5 seconds and integration times on the order of 0.5 seconds are generally entirely adequate to describe the time histories of flyover noise signals with little distortion. However, when the signal durations are appreciably shorter than 10 seconds and, in particular, much less than 5 seconds duration, several sources of error, formerly negligible, may become significant. For example, with short duration flyovers, the half-second sampling interval now becomes an appreciable fraction of the total time history, introducing increased possibilities for errors in sampling the noise levels at the time of maxima and introducing uncertainties in the specification of the maximum angle of radiation. This may result in consequent errors in developing noise level versus distance curves.

Another source of potential error is the relatively long integration time. For short duration samples, a long integration time results in an underestimate of the maximum noise levels. Luckily, compensations occur such that time-integrated noise measures, such as the EPNL or SEL are relatively little distorted. This aspect was discussed in Section IV-B of AMRL TR-73-106 where it is shown that there was little change in EPNL values for time histories having durations of the order of 7 to 15 seconds.

Since it is desired to estimate maximum noise levels (PNL, PNLT and A-levels) as well as integrated measures, processing errors should be minimized so as not to introduce systematic bias in noise level projections. The simplest way to avoid such problems is to obtain initial flyover noise signals that are at least 5 seconds in duration. However, for many military aircraft, the practicable speed ranges for runs at some of the desired thrust ratings are limited, hence high speed runs at relatively low altitudes cannot always be avoided.

When high speeds are unavoidable, one approach is to perform the flight tests at a higher altitude, say 1000 feet rather than 500 feet. When this approach is not feasible, or still results in short duration signals, it may be necessary to employ shorter sampling intervals (and integration times) in data analysis.

The remainder of this appendix presents information on typical durations for military aircraft, as observed from initial sets of Air Force data, several analyses of flyover records obtained for short duration runs, and recommendations for selection of flight altitudes and sampling intervals.

B. TYPICAL DURATION TIMES

As a guide in planning, Figure C-1 shows the trend of measured duration times for jet aircraft (single and multi-engine) and for propeller aircraft, as extracted from recent flyover noise measurements. Regression lines based on observed duration times (defined as the time between 10 dB down points from PNLTM) are plotted in the figure in terms of duration as a function of the ratio of reported aircraft altitude to aircraft speed. One curve represents the duration observed during high thrust runs of jet aircraft (including after-burner, military, and wet-and-dry takeoff conditions). A separate curve shows the durations for jet aircraft at approach and cruise thrust. The remaining curve shows the durations observed for the C-131 propeller aircraft, based on all measured power settings.

C. FLYOVER DATA STUDIES

To examine the possible magnitude of errors involved in processing relatively short duration flyover noise signals, two individual short duration runs were analyzed. For these short duration flyovers, θ values and corresponding spectra were chosen at the time of the maximum PNLT value and also at times of 0.5 second preceding and following the maximum PNLT value. The first run was that of an F-100 at cruise power, with a signal duration of 6.7 seconds. The second case chosen was a C-135A run at cruise thrust with a signal duration of 1.8 seconds.

Results for the F-100 run analysis are shown in Figure C-2 through C-6. Figure C-2 shows the spectra and θ values while Figure C-3 through C-6 show the resulting noise levels versus distance curves. For this run, maximum values of PNLT, PNL, A-levels and D-levels coincided, with the unusual complication that the maximum PNL value was observed for two samples, PNLTM and the succeeding time interval (PNLTM + 0.5 seconds).

At large distances, there are sizable differences between the maximum noise level measure curves (PNLT, PNL and A-level) but little difference in the EPNL curves (see Figure C-6). Selection of θ and the corresponding spectra occurring 0.5 seconds before the PNLM results in a projection of lower levels at larger distances. For this particular example, selection of the θ and spectrum occurring 0.5 seconds after PNLTM results in values slightly higher than the noise level projections based on the PNLT values. (This illustrates the unusual case where there were two spectra having equal PNLM values.)

Figures C-7 through C-12 shows the results of a similar analysis of the C-135A cruise thrust run. Spectrum differences (see Figure C-7) are greater, as are the angle differences. As a consequence, differences in projected PNLT, PNL and A-levels are considerably greater over the entire distance range. Again Figure C-11 and C-12 show that differences in EPNL and SEL values are relatively small.

The effects of shortening sampling intervals and integration times in analysis of short duration flyovers was examined by analysis of data from two C-135A runs. For these runs, the recorded noise flyover data had been processed using sampling intervals (and integration times) of 0.5, 0.25, and 0.125 seconds. Figures C-13 through C-18 show the results of one run (72-025-006-01), while Figures C-19 through C-24 show the results for run 72-025-006-03.

The resulting spectra for the various integration times (see Figures C-13 and C-19) show only minor differences with changes in sampling interval. The resulting projections of PNLT, PNL, and A-levels show differences of the order of 2 dB with the higher levels occurring for the shorter integration time as expected. Typically, the differences are slightly greater at shorter distances than at larger distances. Thus the average spread in levels for the three integration times was 2.0 dB at 500 feet, and 1.8 dB at 5,000 feet (as based on an average of differences in PNLT, PNL and A-level measures).

The EPNL and SEL projections show smaller differences with integration time, again as anticipated. The differences tend to increase at the larger distance. Thus the average spread for the EPNL and SEL values for the two runs with integration time was 0.6 dB at 500 feet and 1.5 dB at 5,000 feet.

D. SUMMARY AND RECOMMENDATIONS

The analyses of relatively short duration flyover signals (less than 5 seconds) show that sizable errors can occur in projections of maximum noise levels (PNLT, PNL and A-levels) due to possible errors in selecting the proper time at which the maximum noise levels occur. Errors also occur due to the relatively long sampling intervals (and integration times). The resulting errors in projected EPNL and SENEL values are, fortunately, quite small. However, to minimize the underestimate of maximum noise levels the following recommendations are given.

1. Using the duration estimates provided in Figure C-1, select altitudes and speeds such that the expected flyover signal duration would be in excess of 5 seconds. When this is not feasible, sampling intervals should be chosen in accordance with the following:

Duration, d, in seconds	Sampling Interval and Integration Time, in seconds
$d \geq 5$	0.5
$5 > d > 2$	0.25
$d \leq 2$	0.125

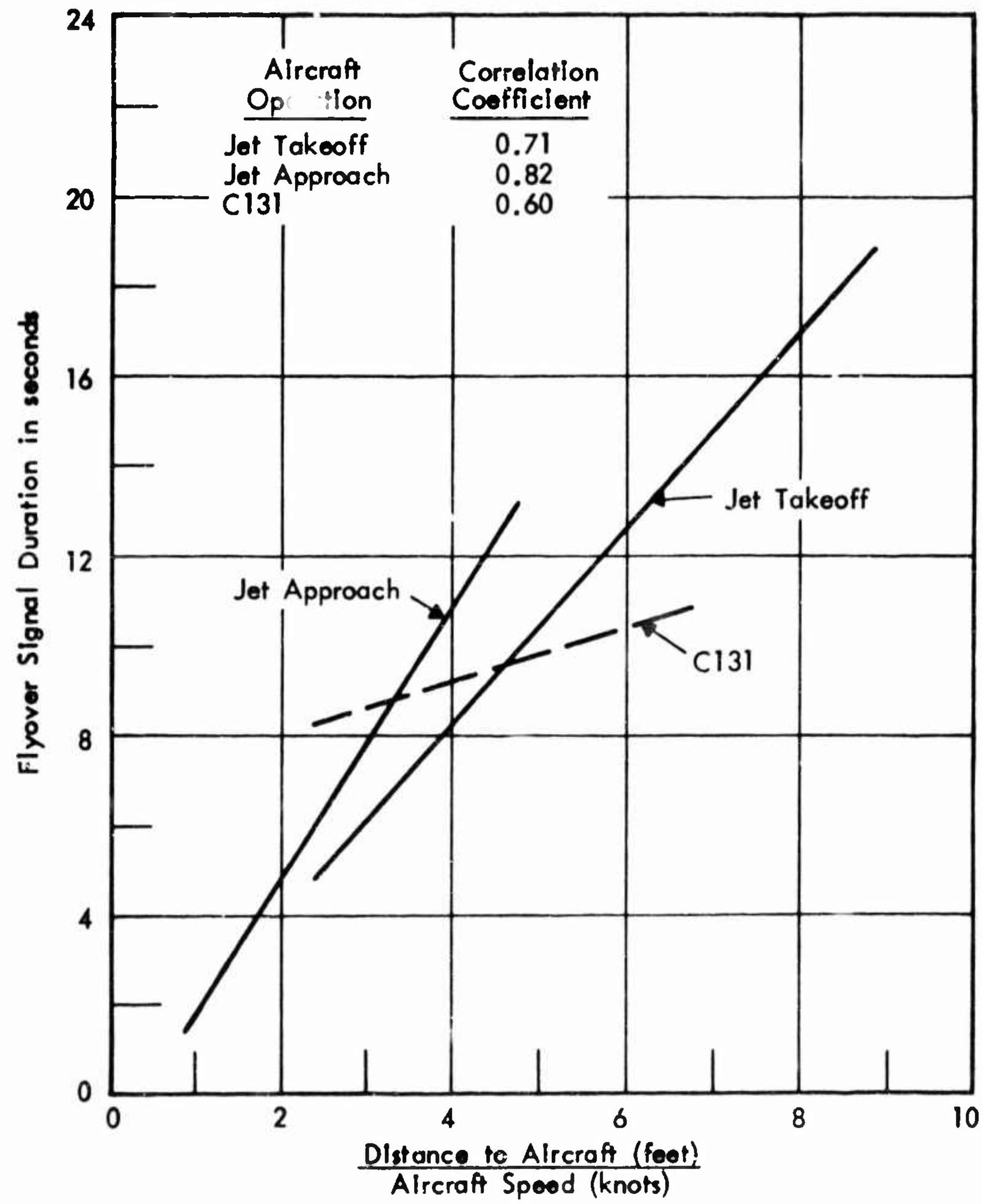


FIGURE C-1. FLYOVER SIGNAL DURATION AS A FUNCTION OF AIRCRAFT ALTITUDE AND SPEED

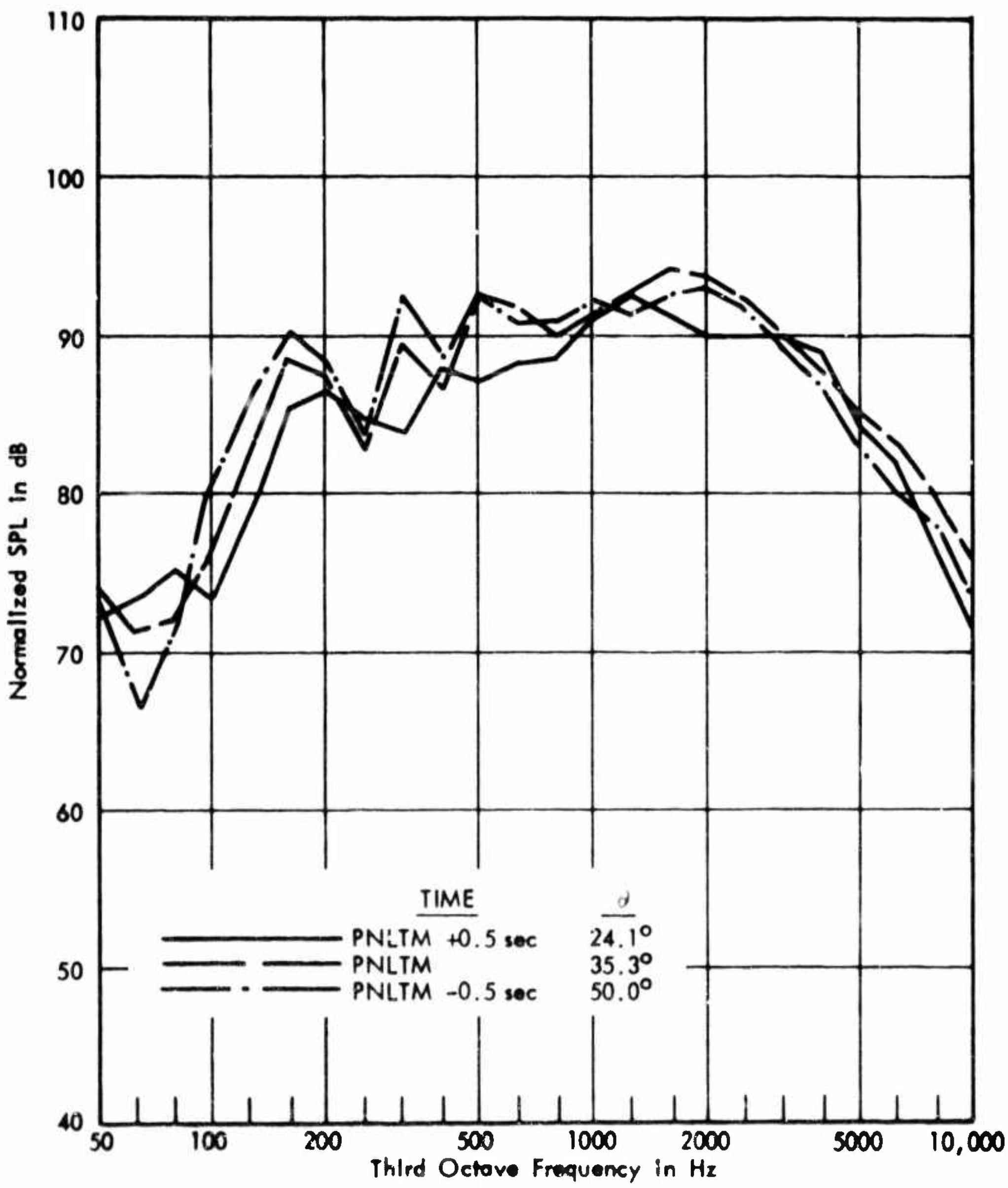


FIGURE C-2. NORMALIZED FLYOVER NOISE SPECTRA FOR DIFFERENT TIMES - F100, CRUISE THRUST, 400 FEET, 370 KNOTS (Run 72-030-002-02)

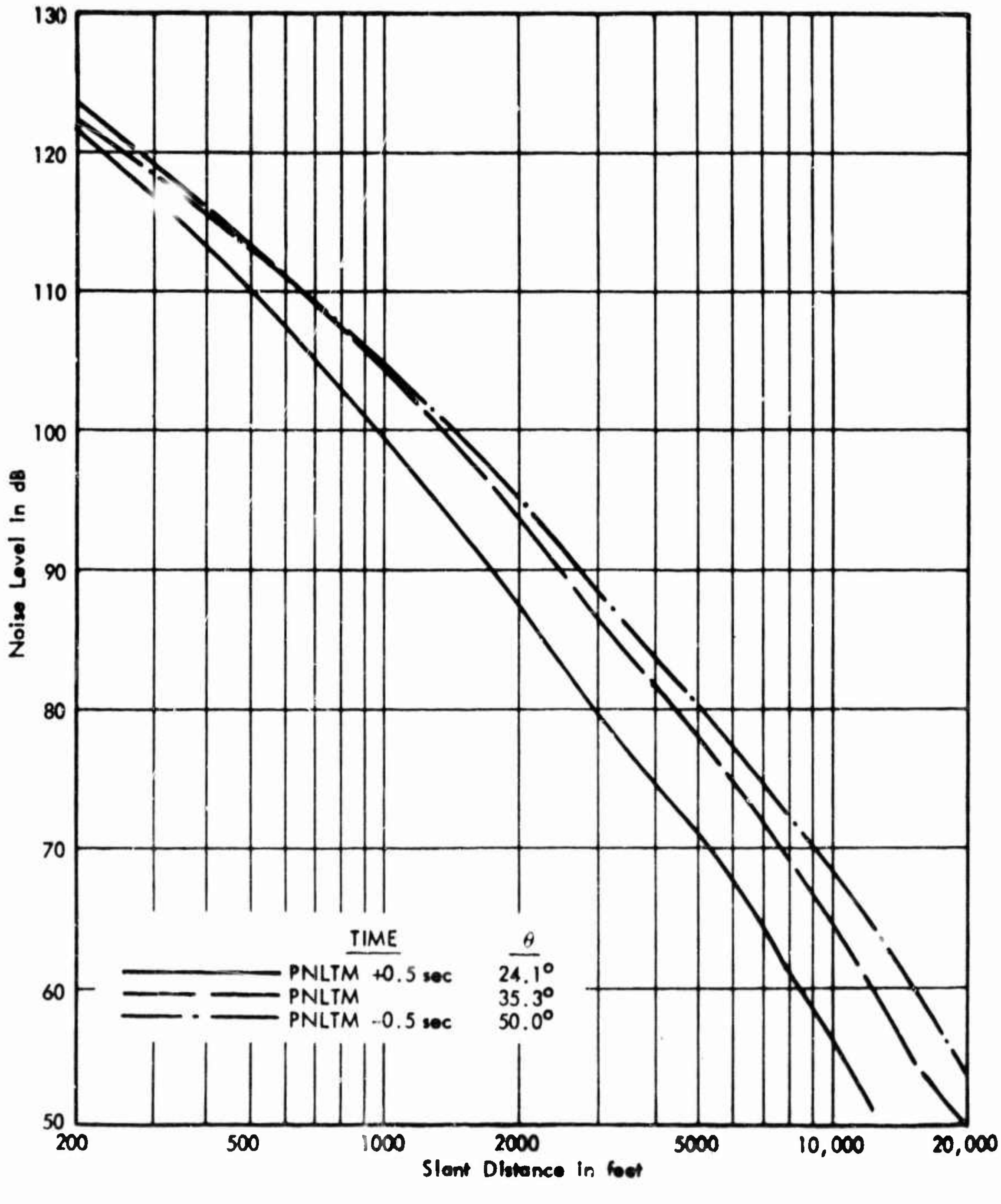


FIGURE C-3. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - F100, CRUISE THRUST, 400 FEET, 370 KNOTS (RUN 72-030-002-02

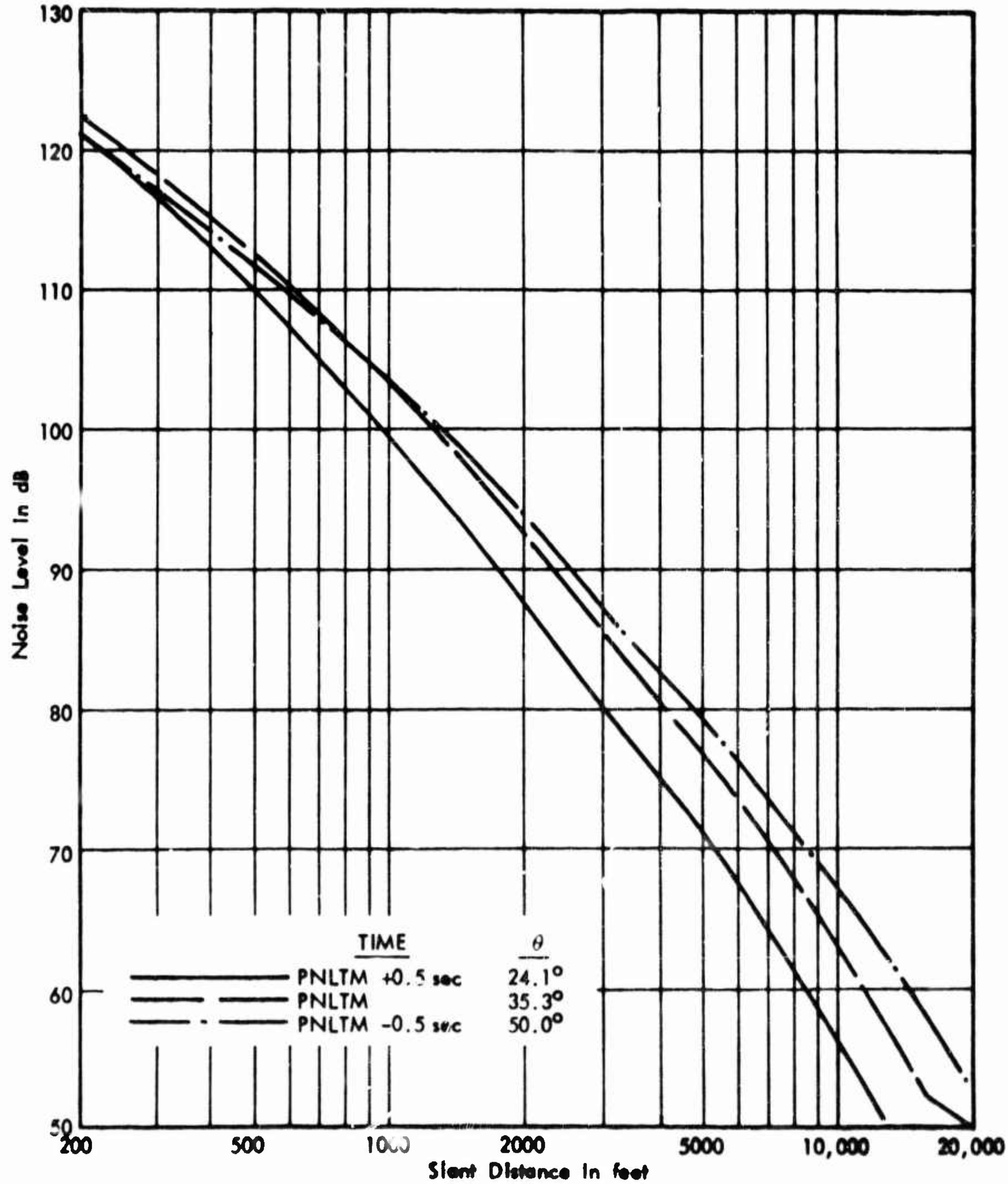


FIGURE C-4. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - F100, CRUISE THRUST, 400 FEET, 370 KNOTS (RUN 72-030-002-02)

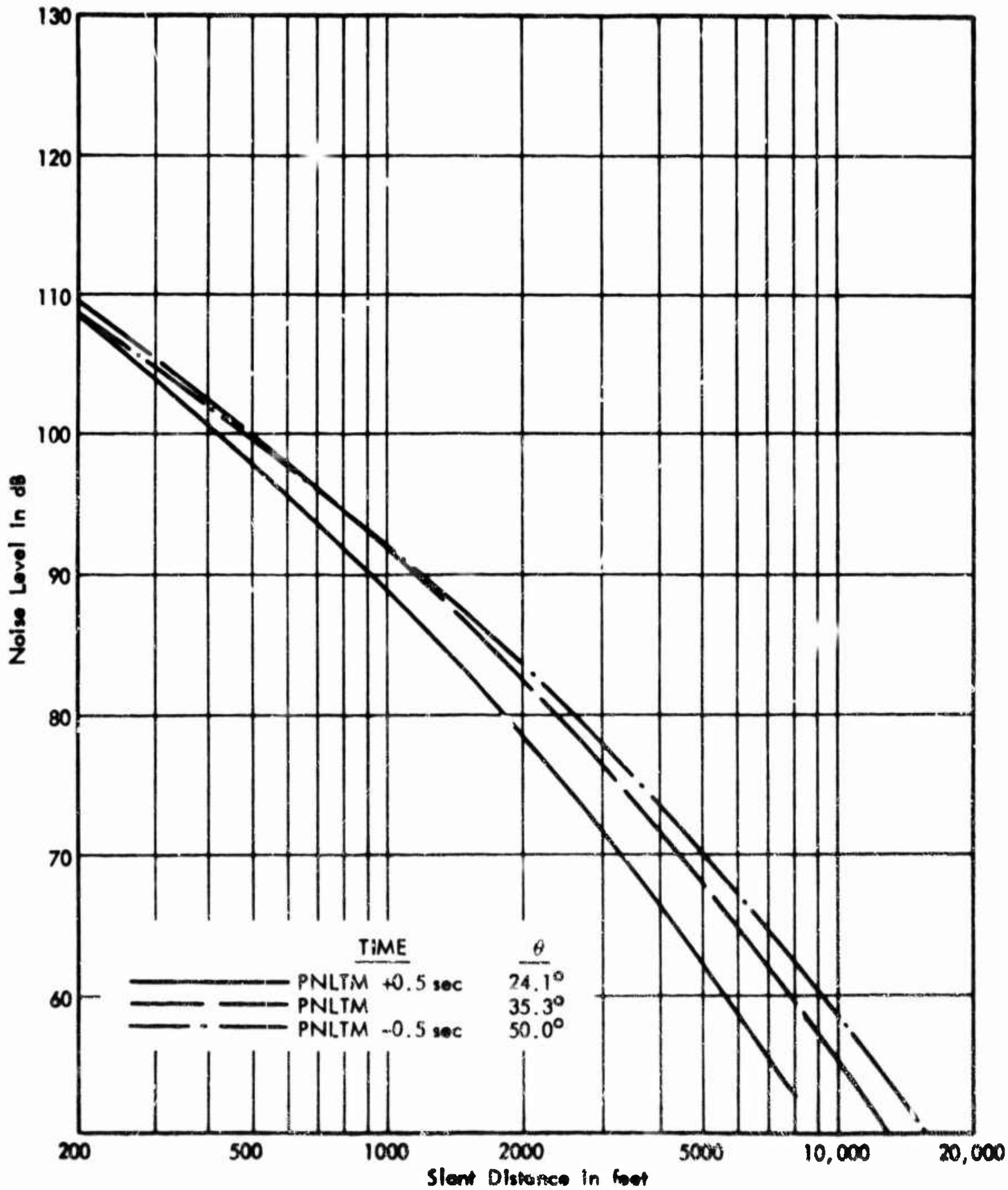


FIGURE C-5. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - F100, CRUISE THRUST, 400 FEET, 370 KNOTS (RUN 72-030-002-02)

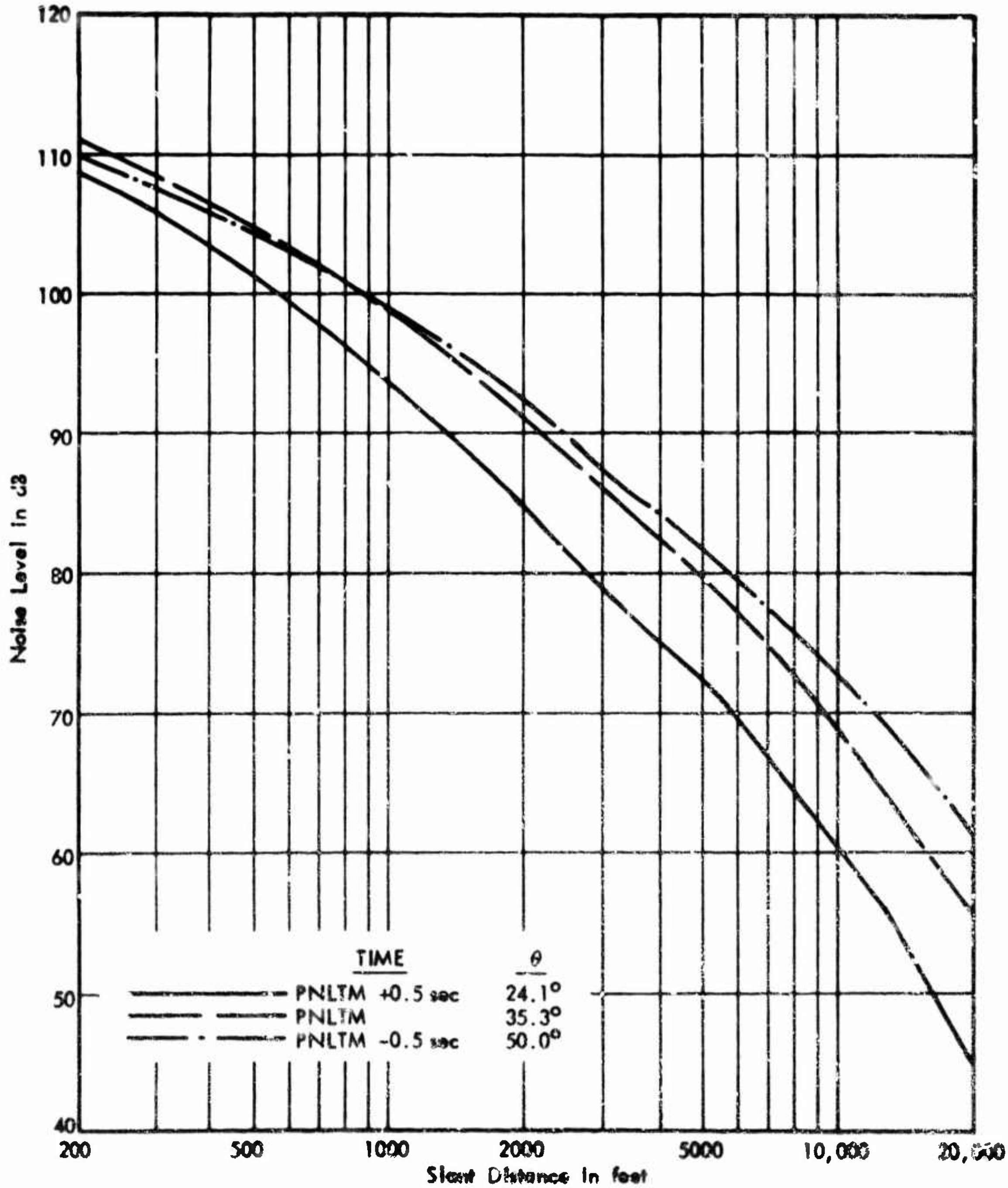


FIGURE C-6. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - F100, CRUISE THRUST, 400 FEET, 370 KNOTS (RUN 72-030-002-02)

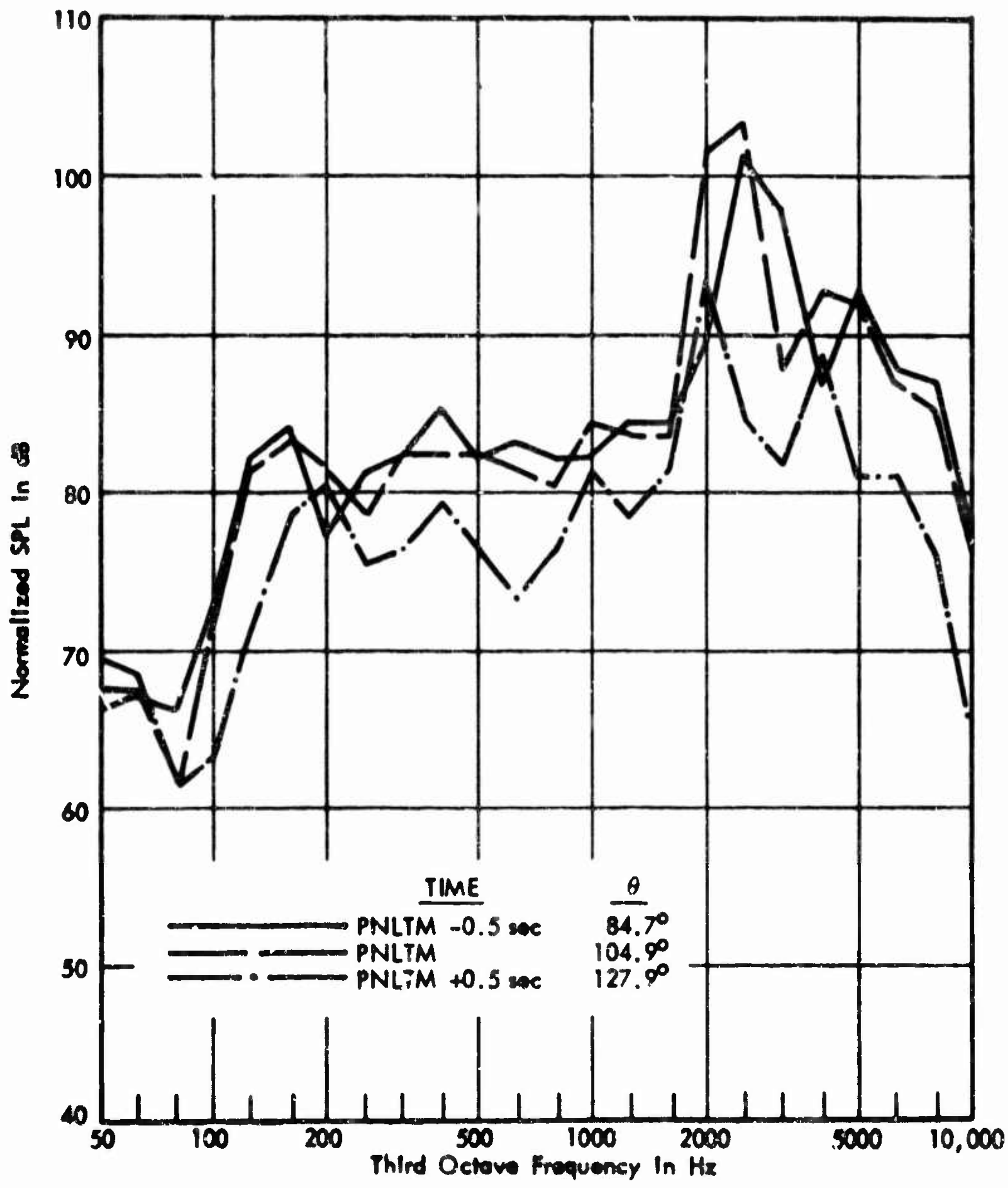


FIGURE C-7. NORMALIZED FLYOVER NOISE SPECTRA FOR DIFFERENT TIMES, C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

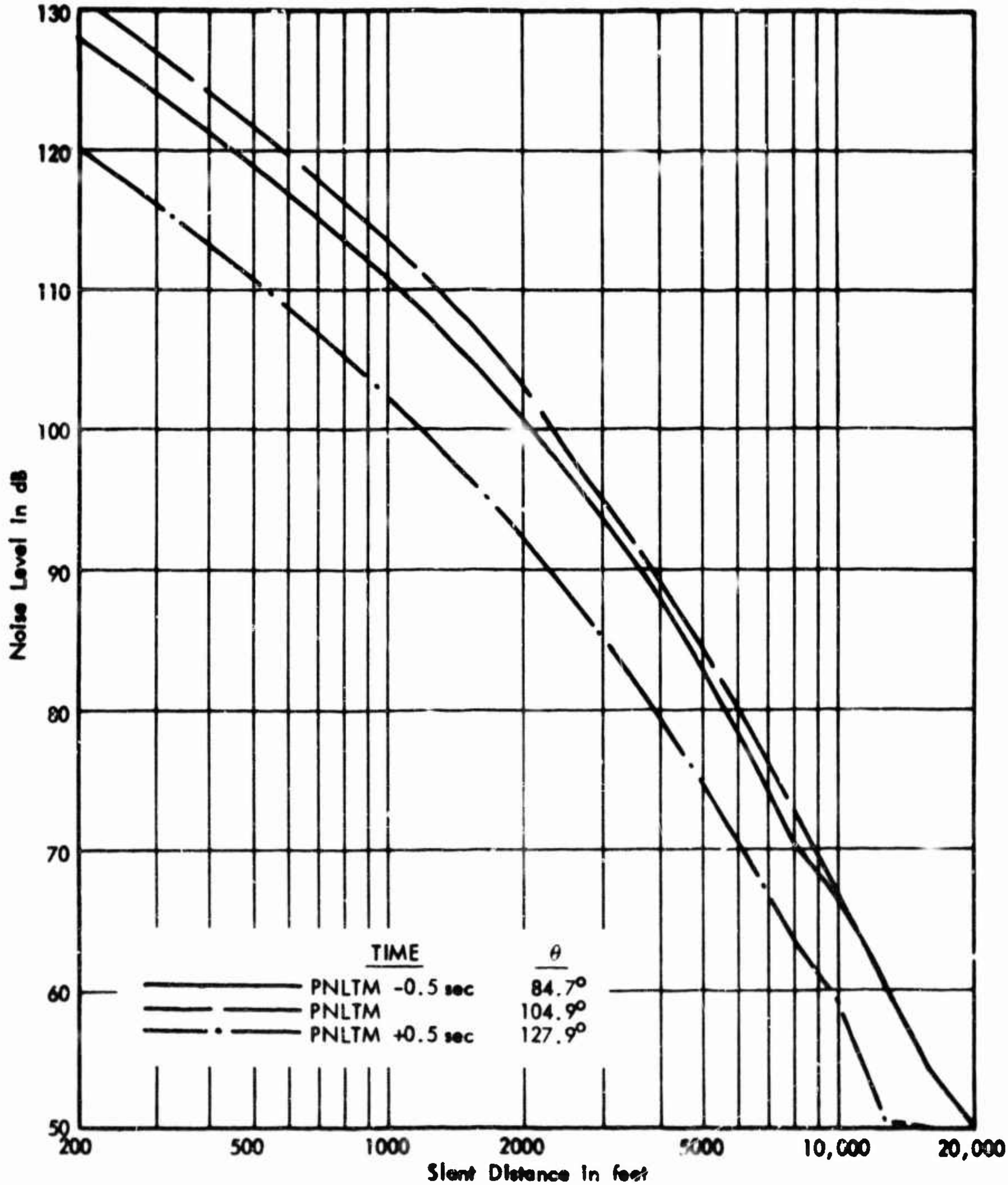


FIGURE C-8. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

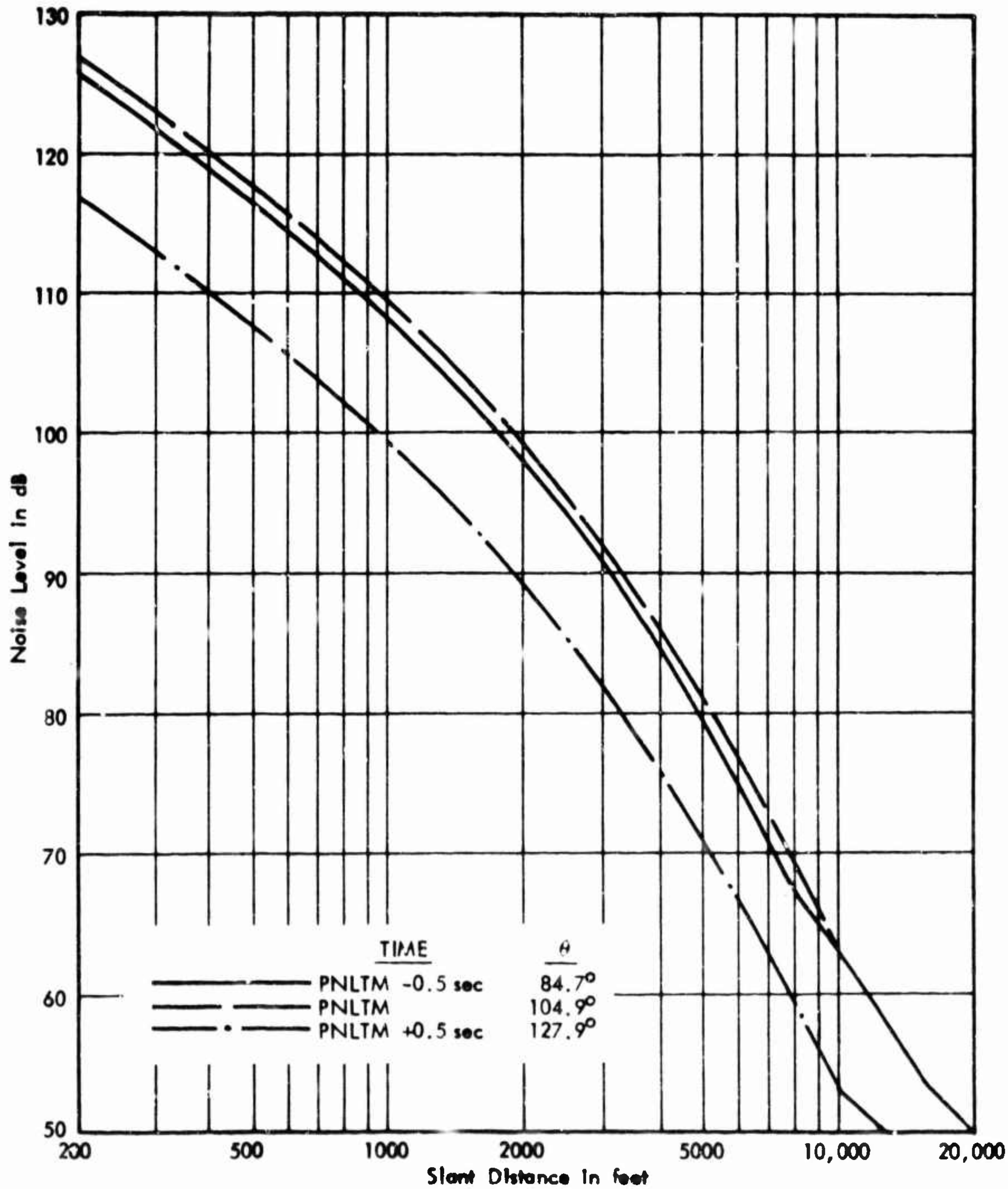


FIGURE C-9. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

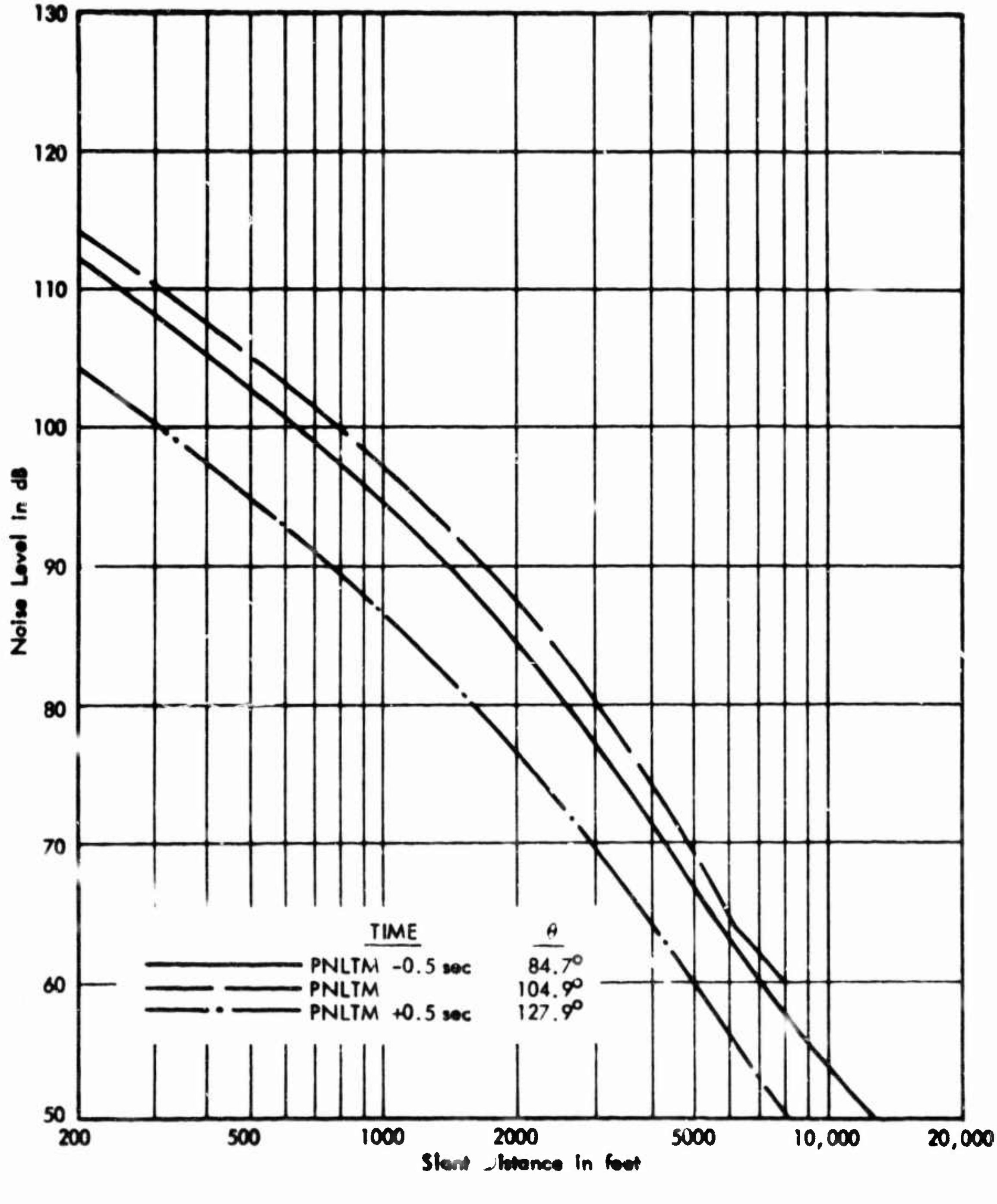


FIGURE C-10. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

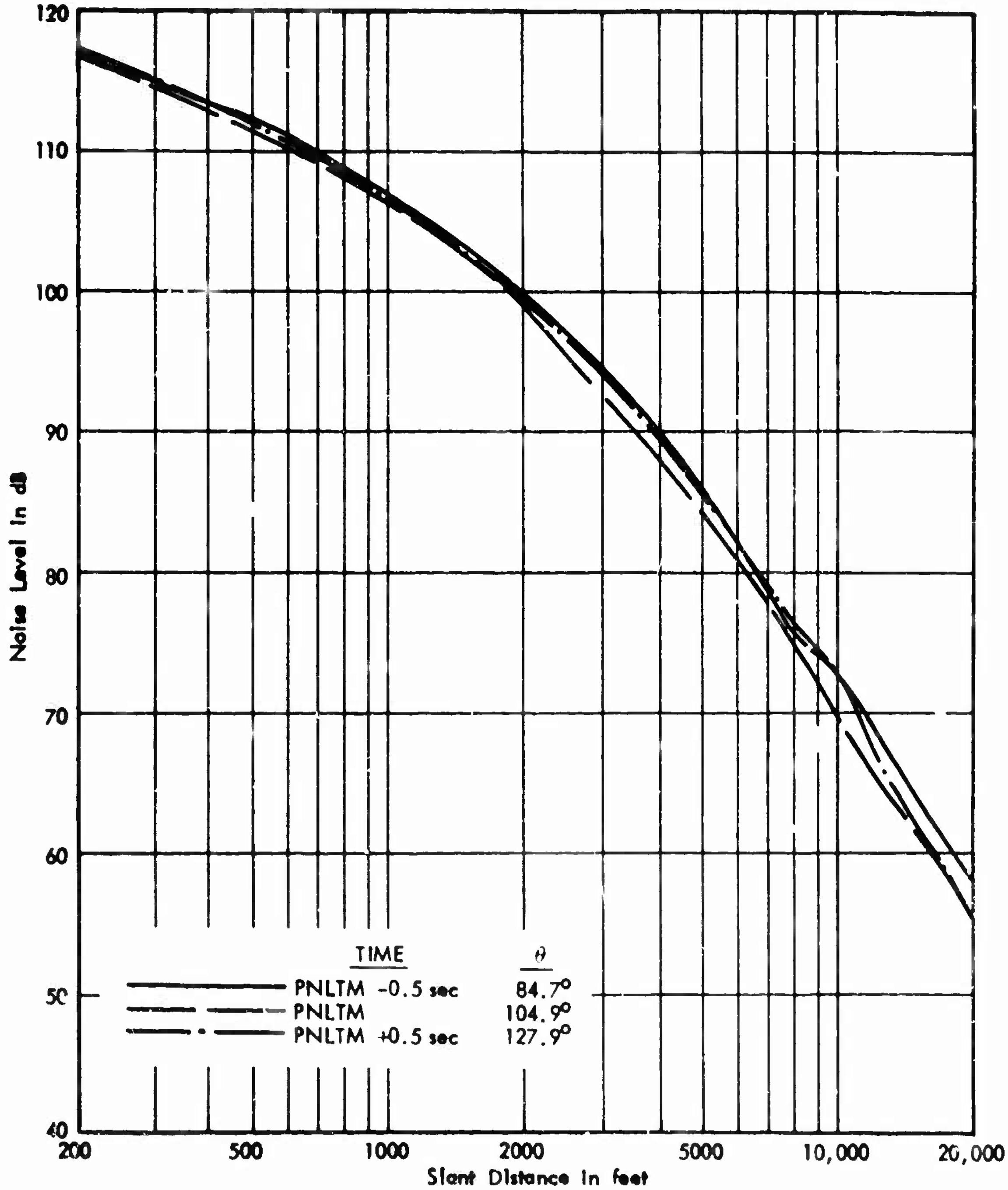


FIGURE C-11. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

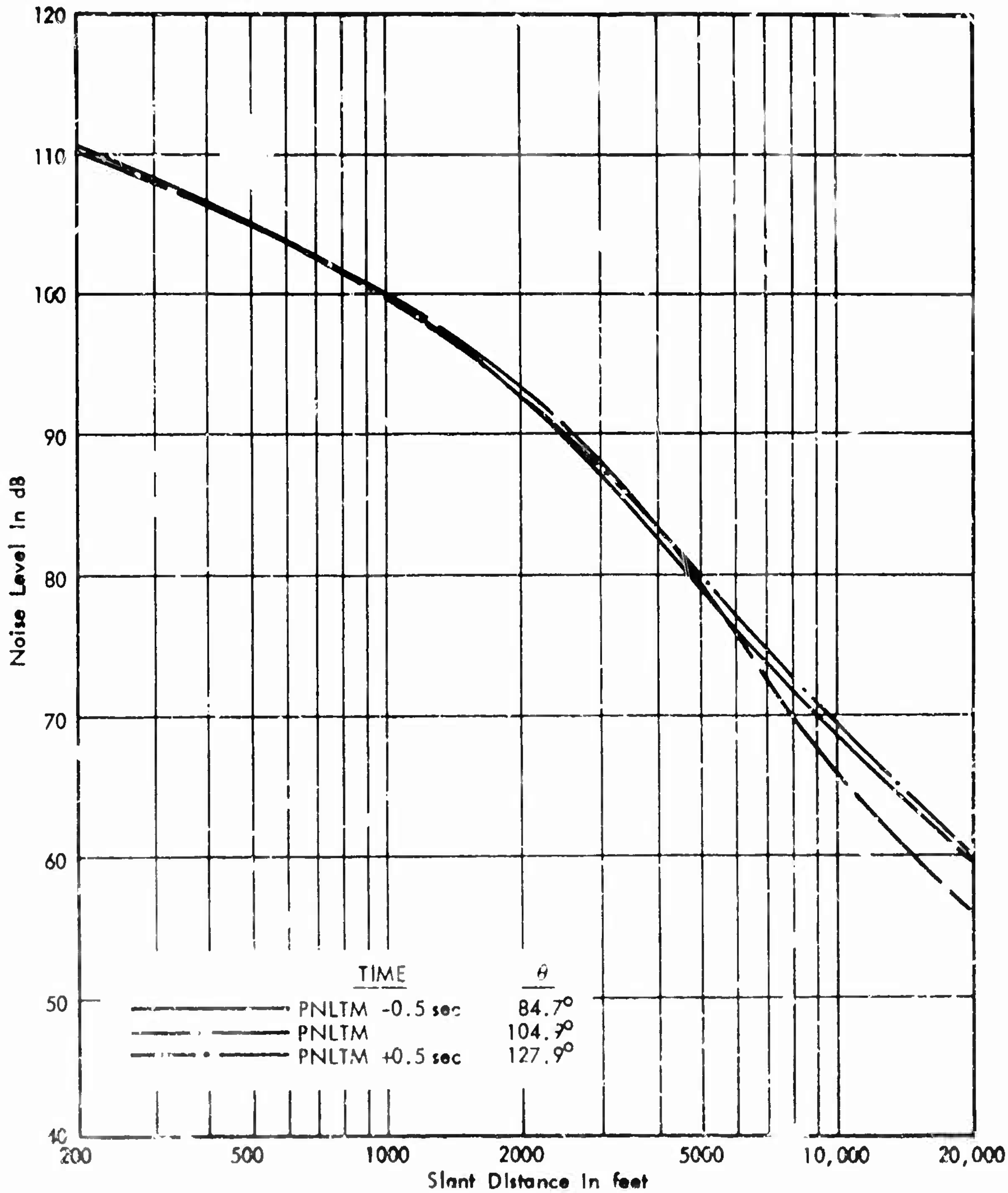


FIGURE C-12. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT TIMES - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-525-006-01)

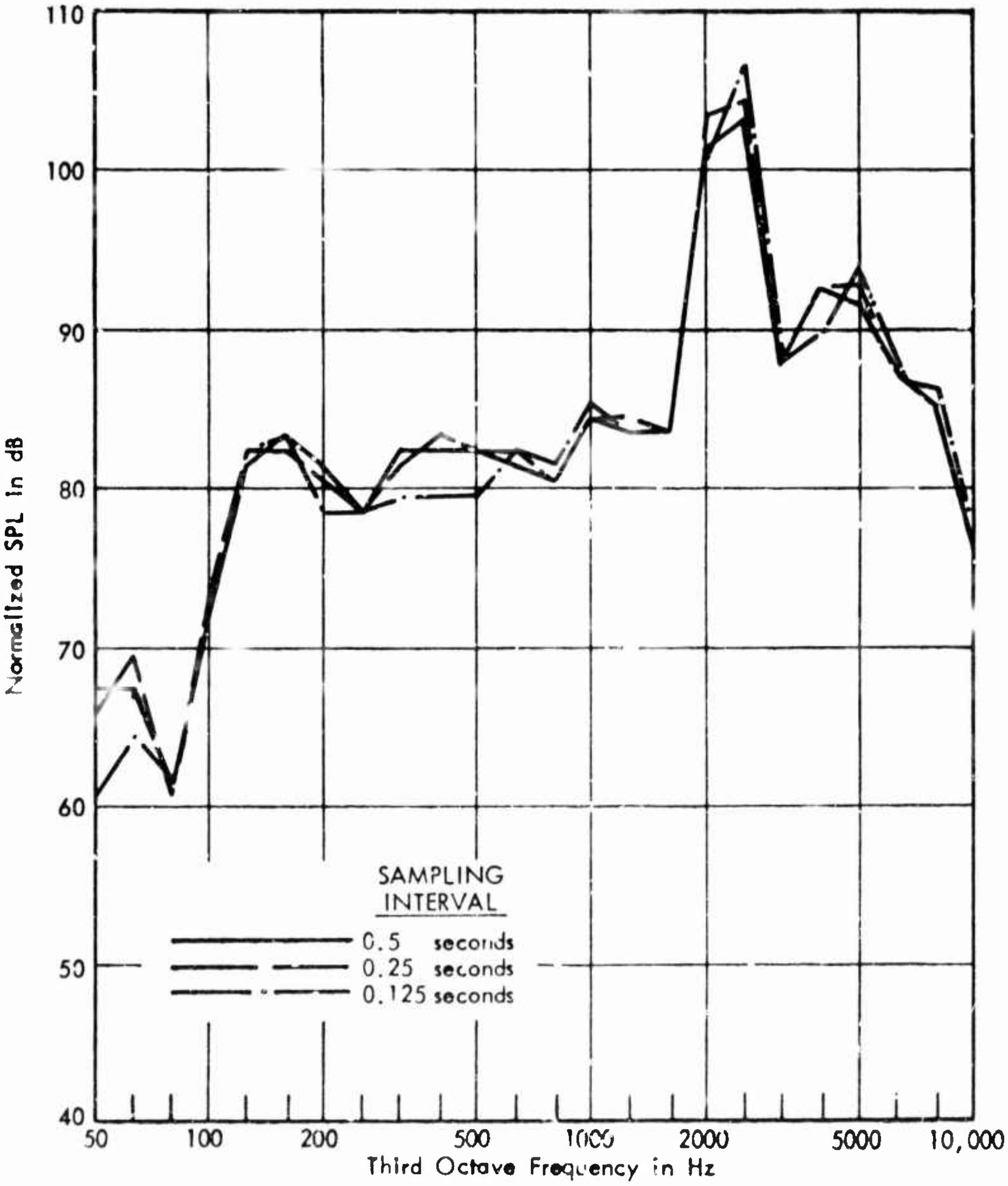


FIGURE C-13. NORMALIZED FLYOVER NOISE SPECTRA FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 22-025-006-01)

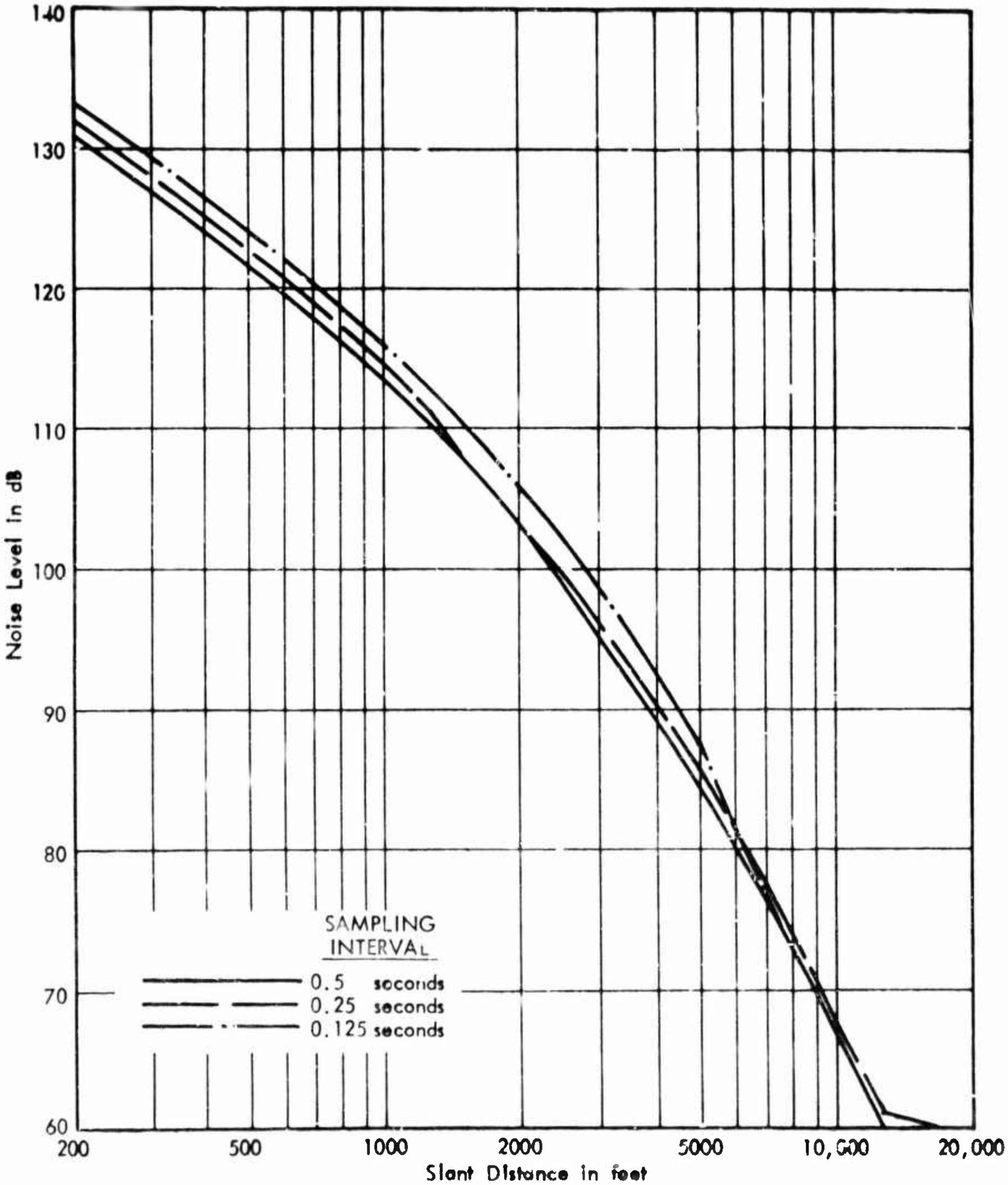


FIGURE C-14. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

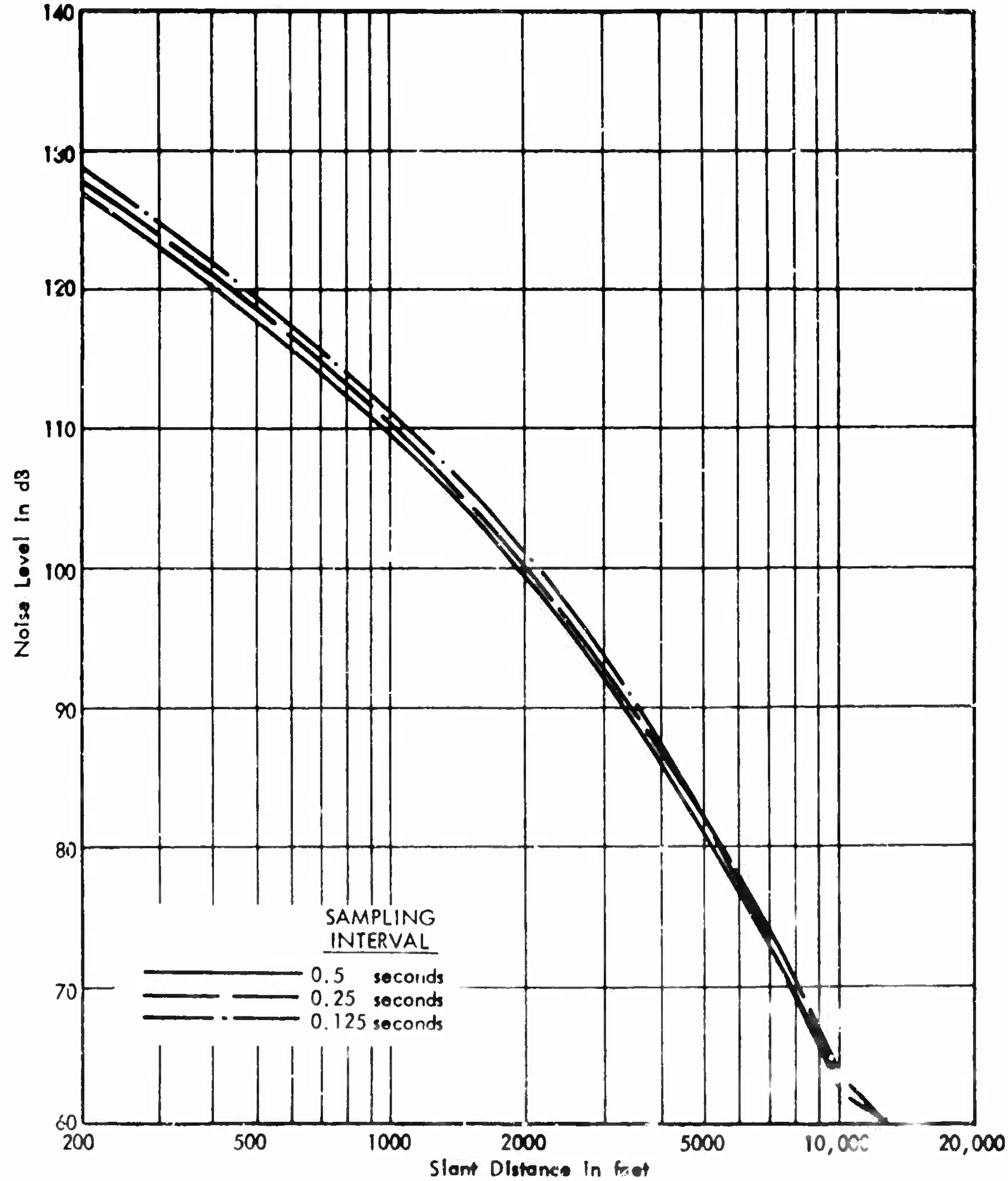


FIGURE C-15. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS, (RUN 72-025-006-01)

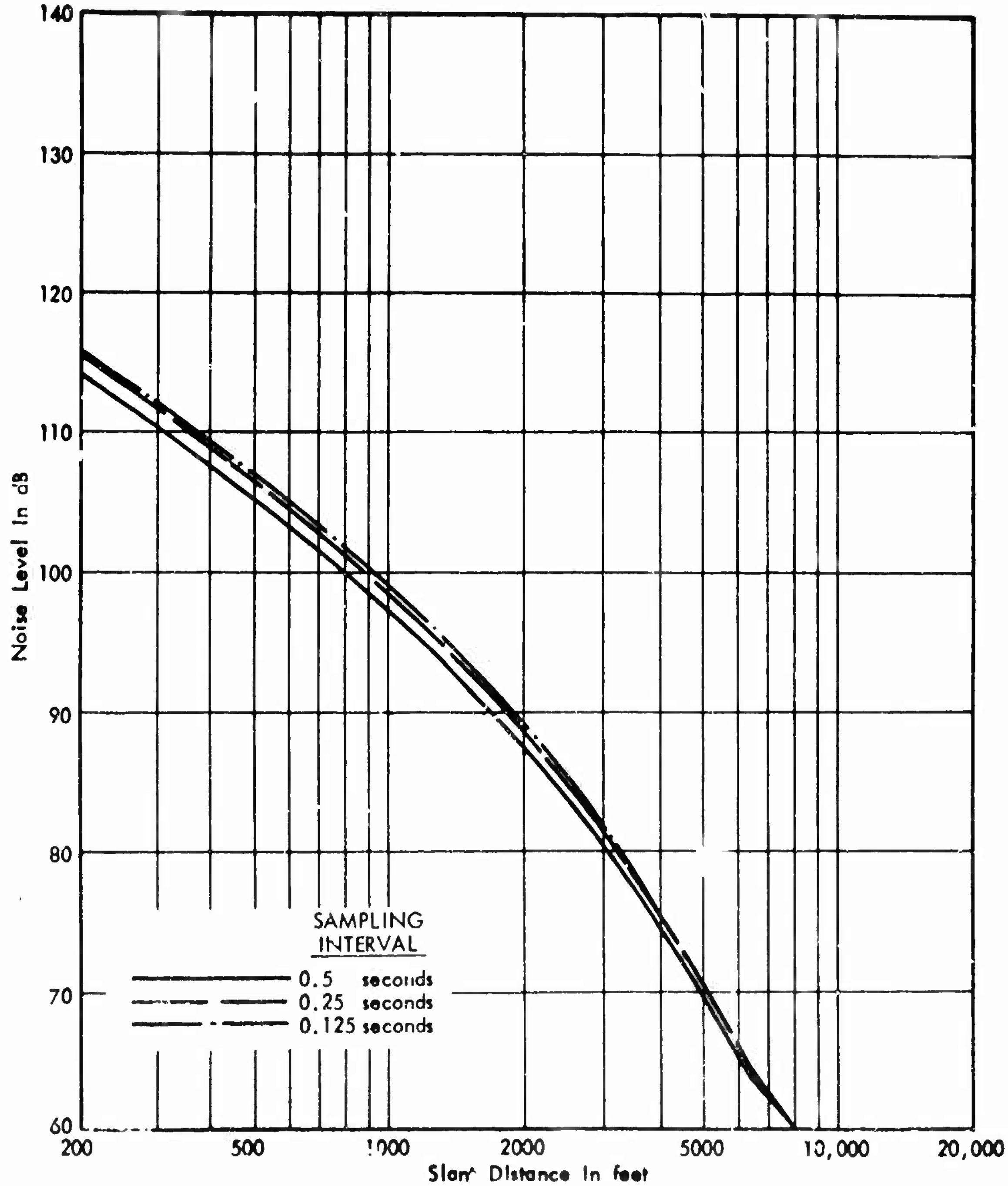


FIGURE C-16. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

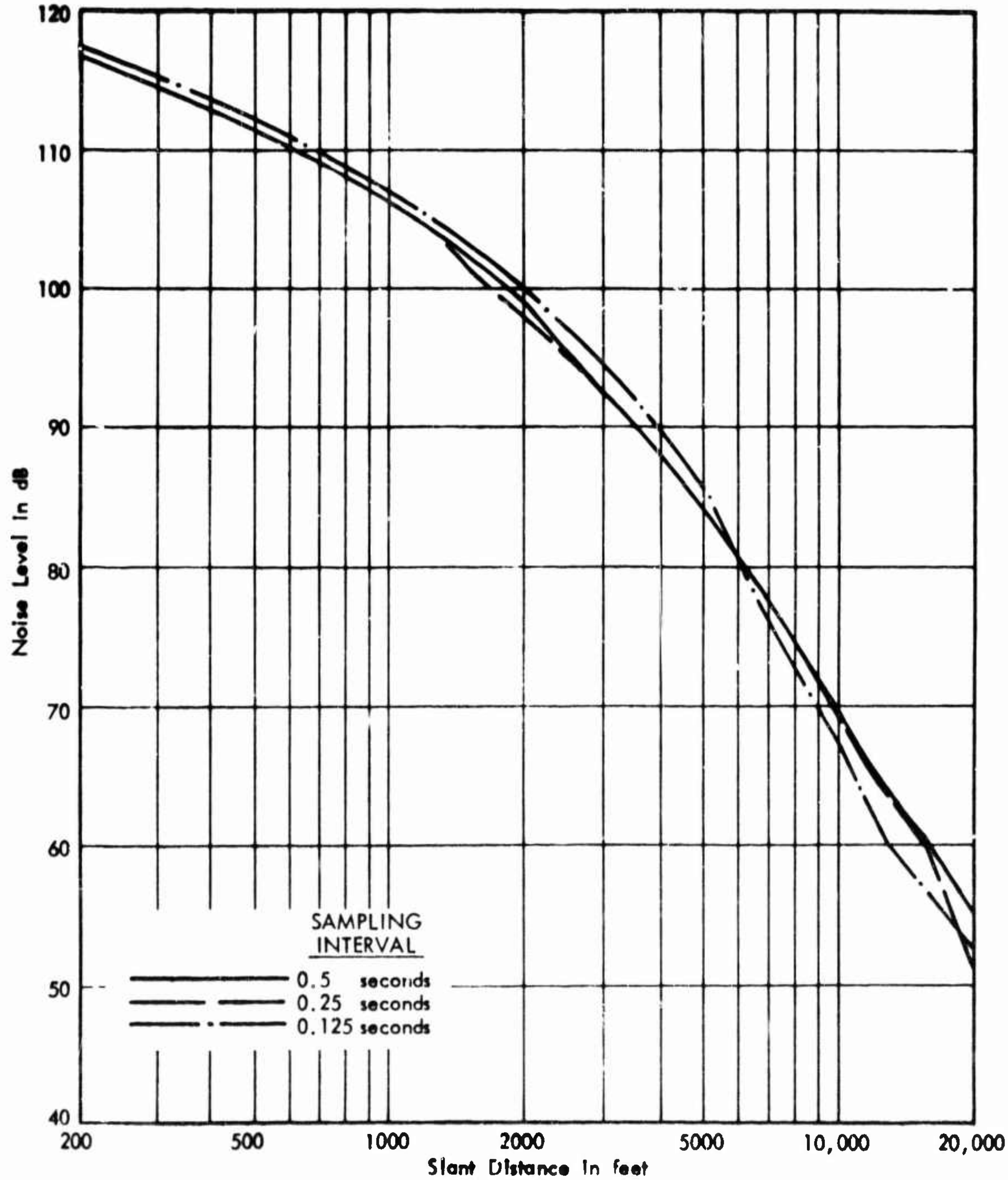


FIGURE C-17. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

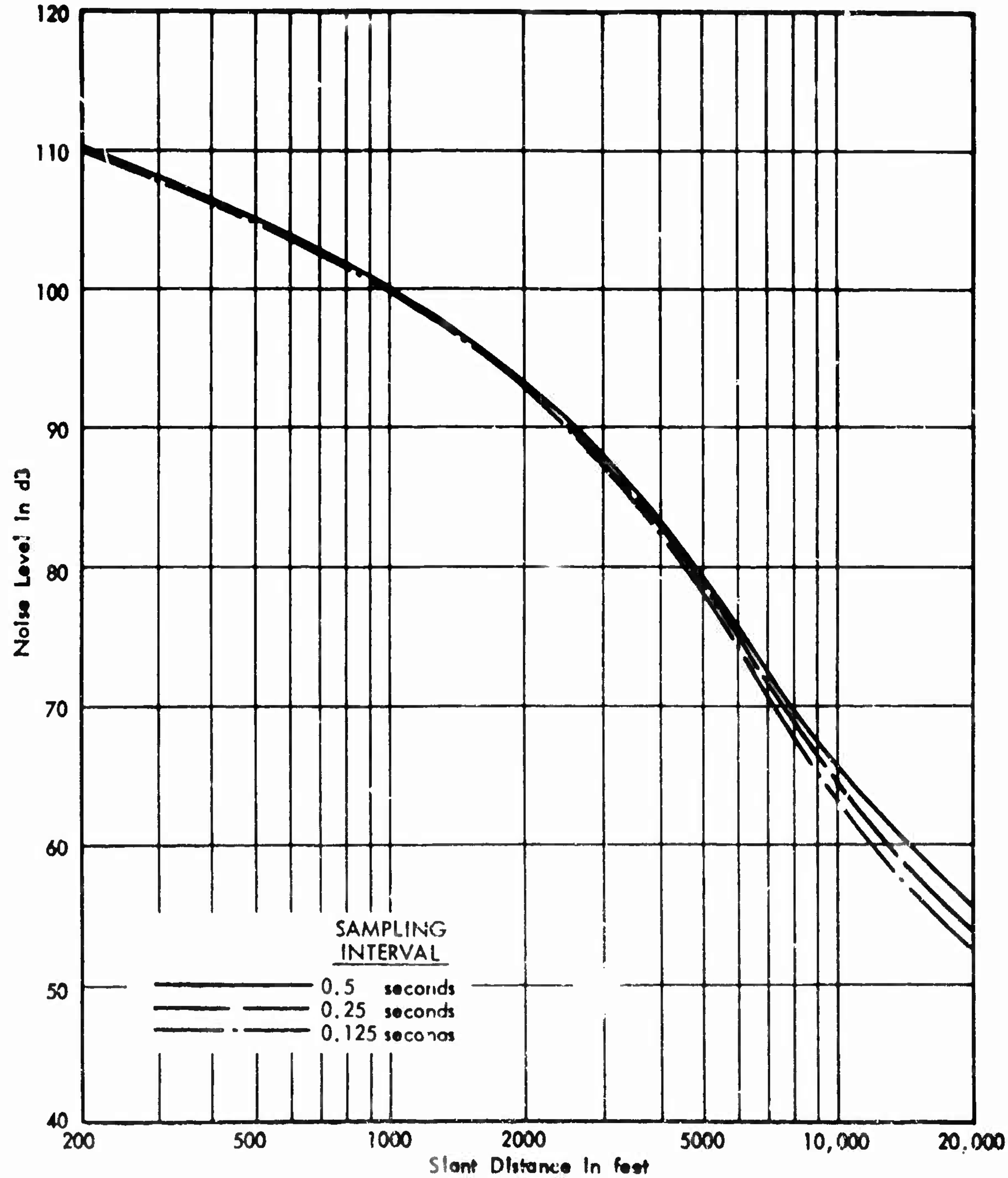


FIGURE C-18. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-01)

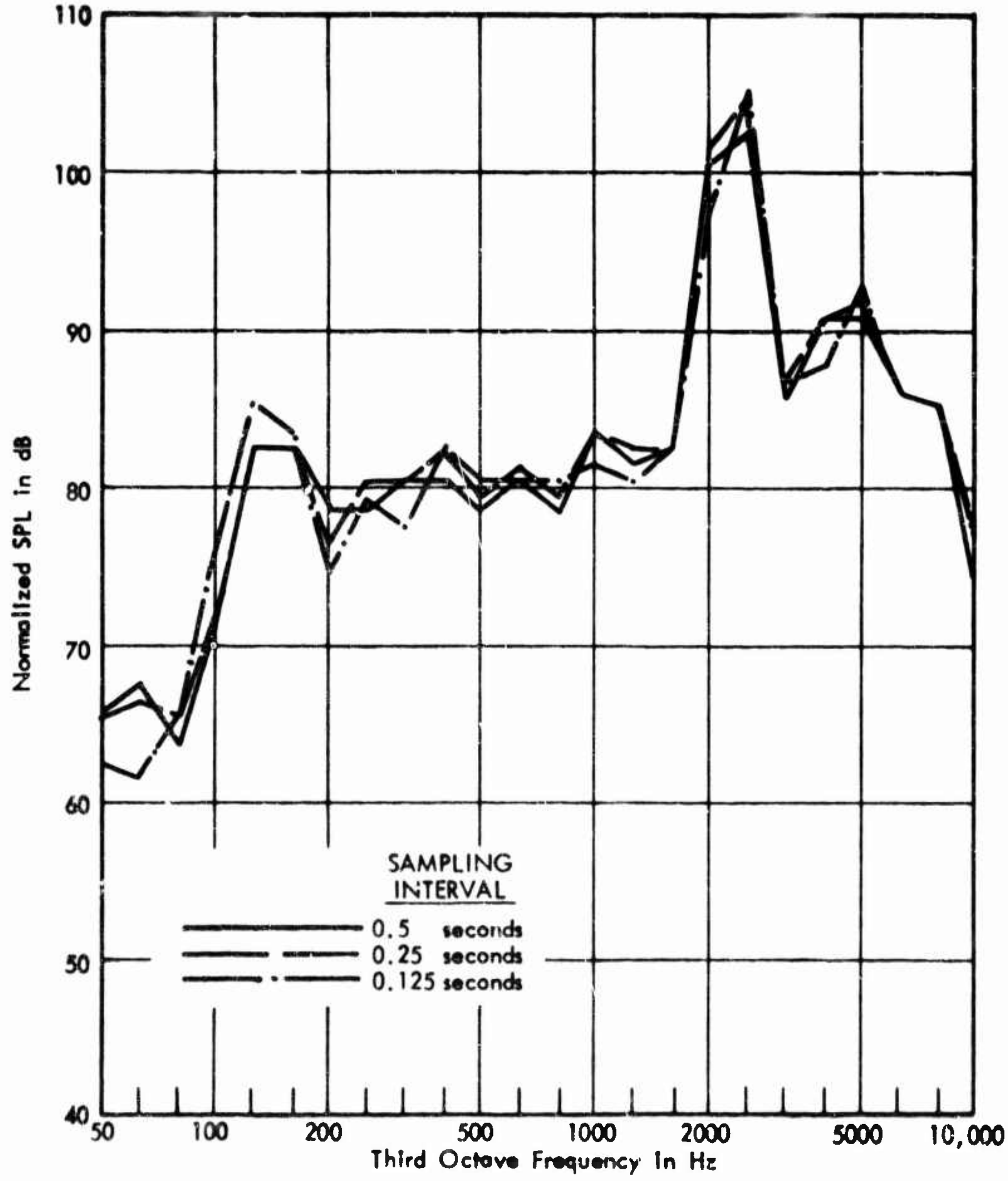


FIGURE C-19. NORMALIZED FLYOVER NOISE SPECTRA FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-03)

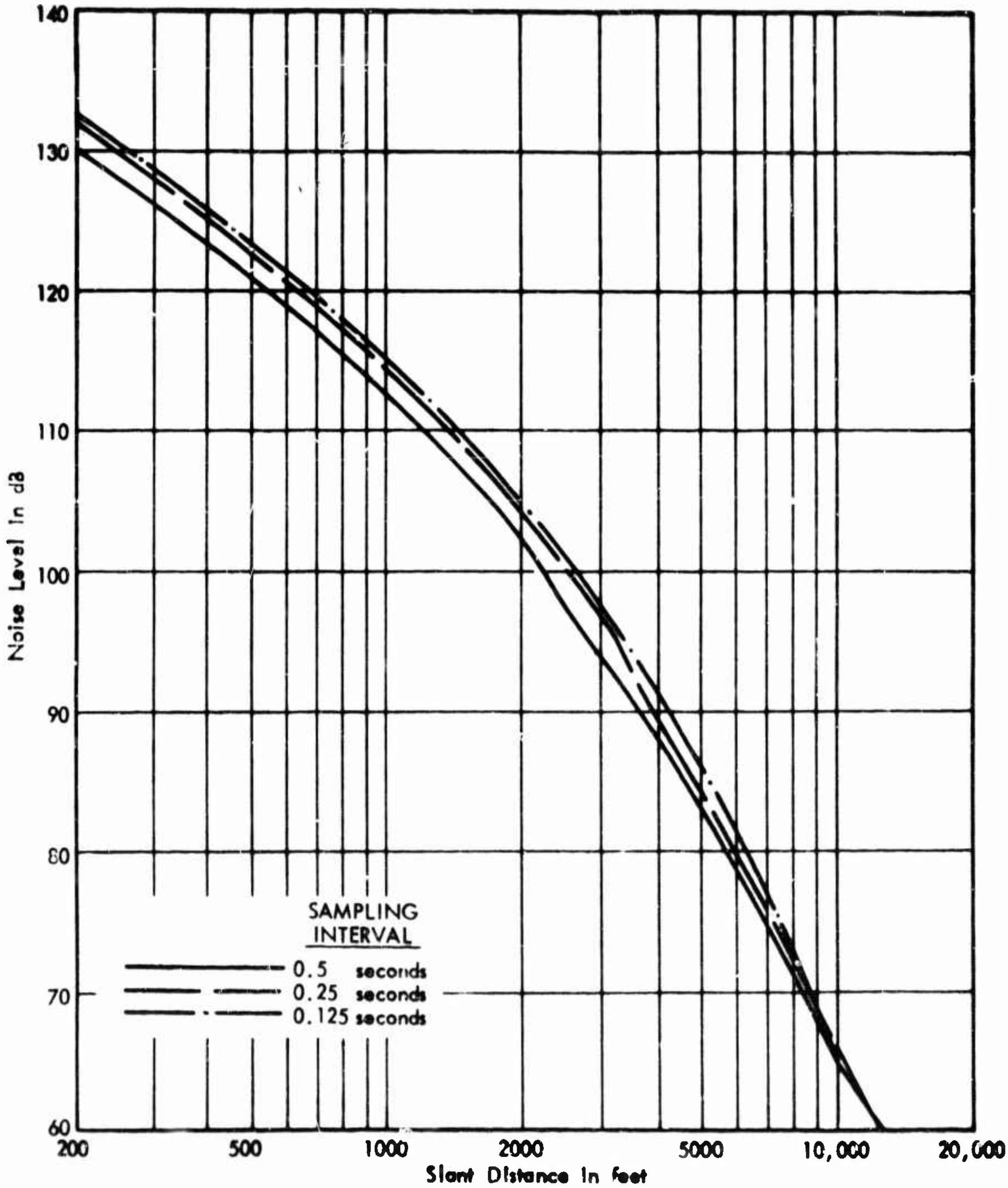


FIGURE C-20. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST 400 FEET, 300 KNOTS (RUN 72-025-006-03)

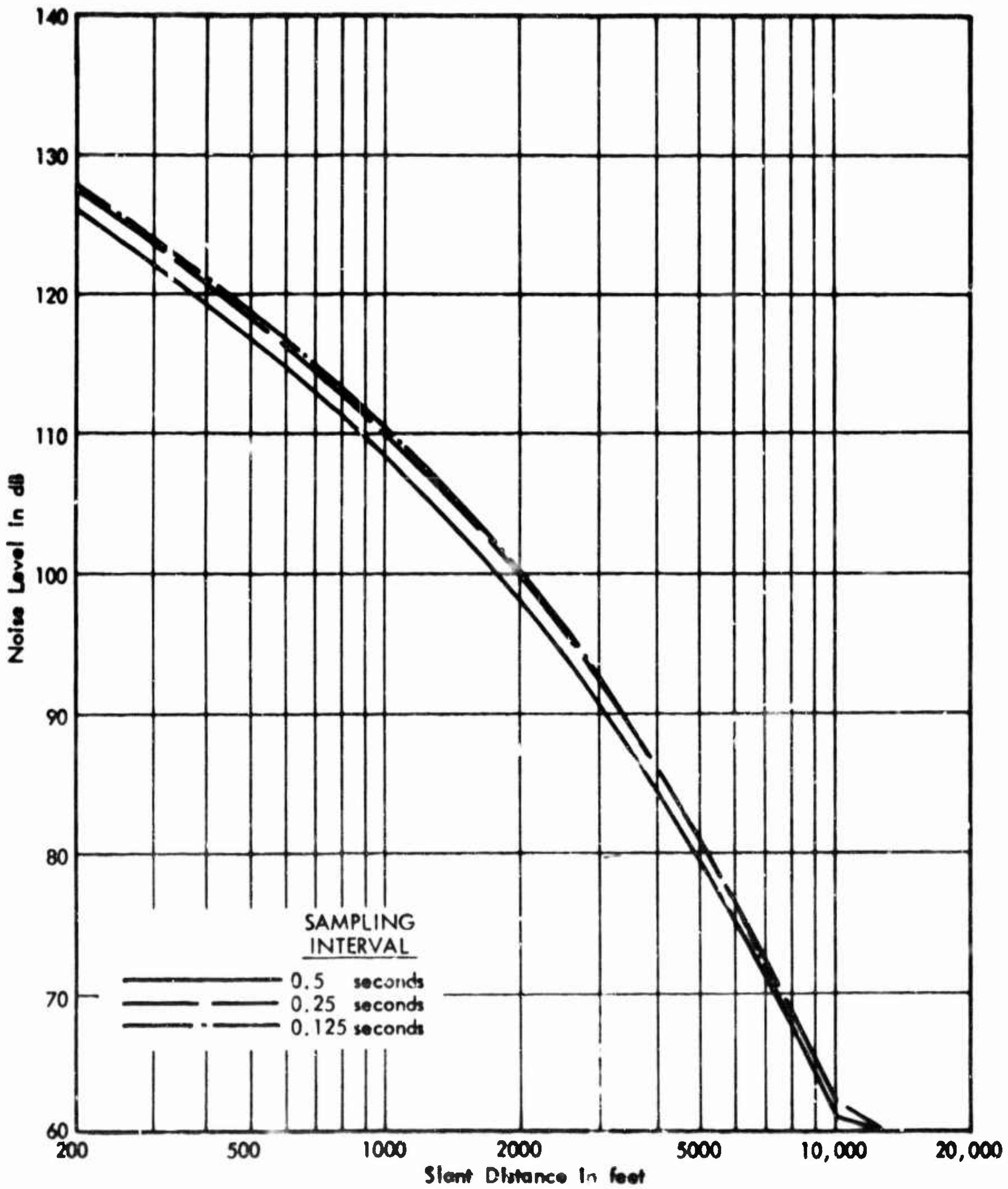


FIGURE C-21. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-03)

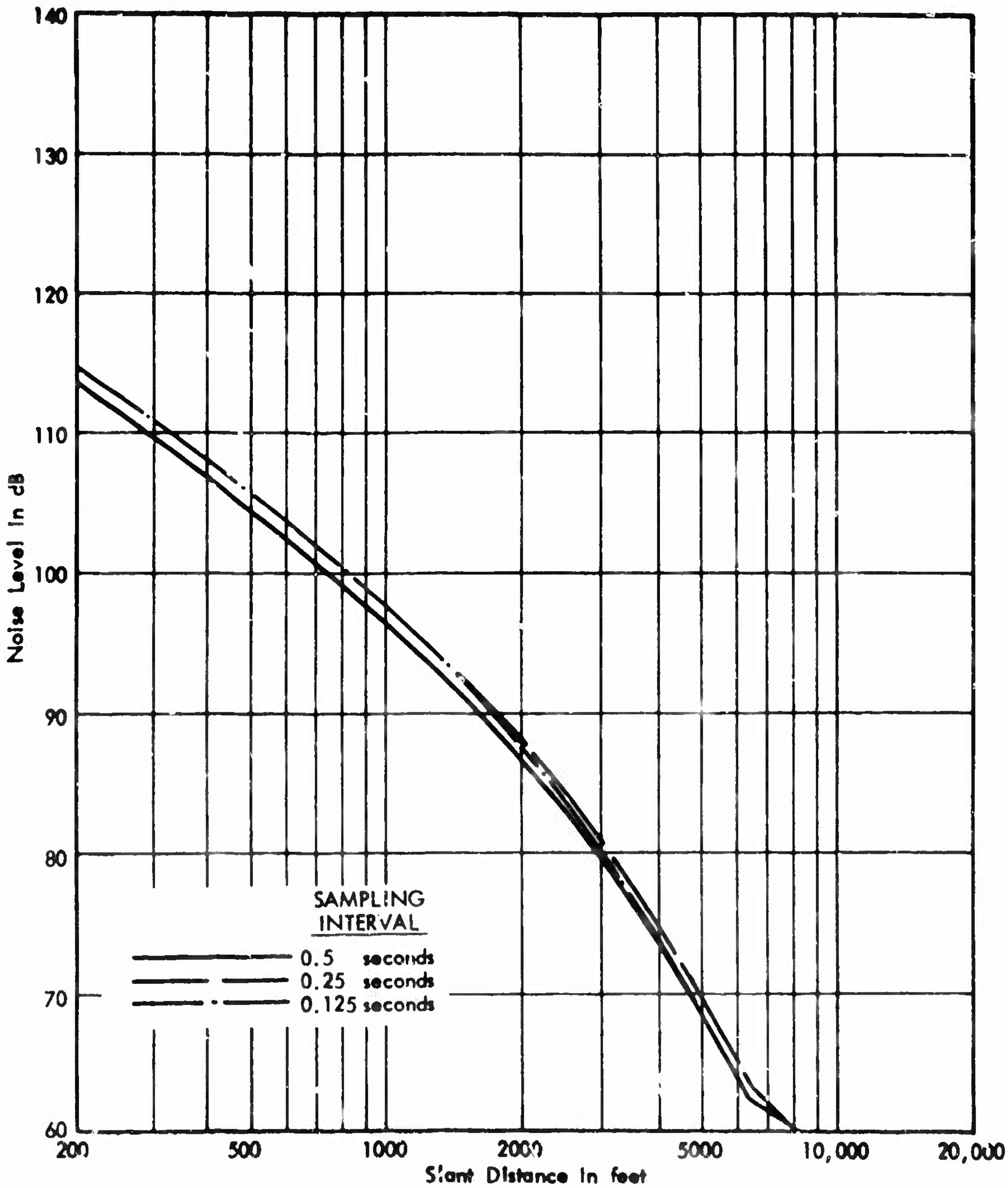


FIGURE C-22. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-03)

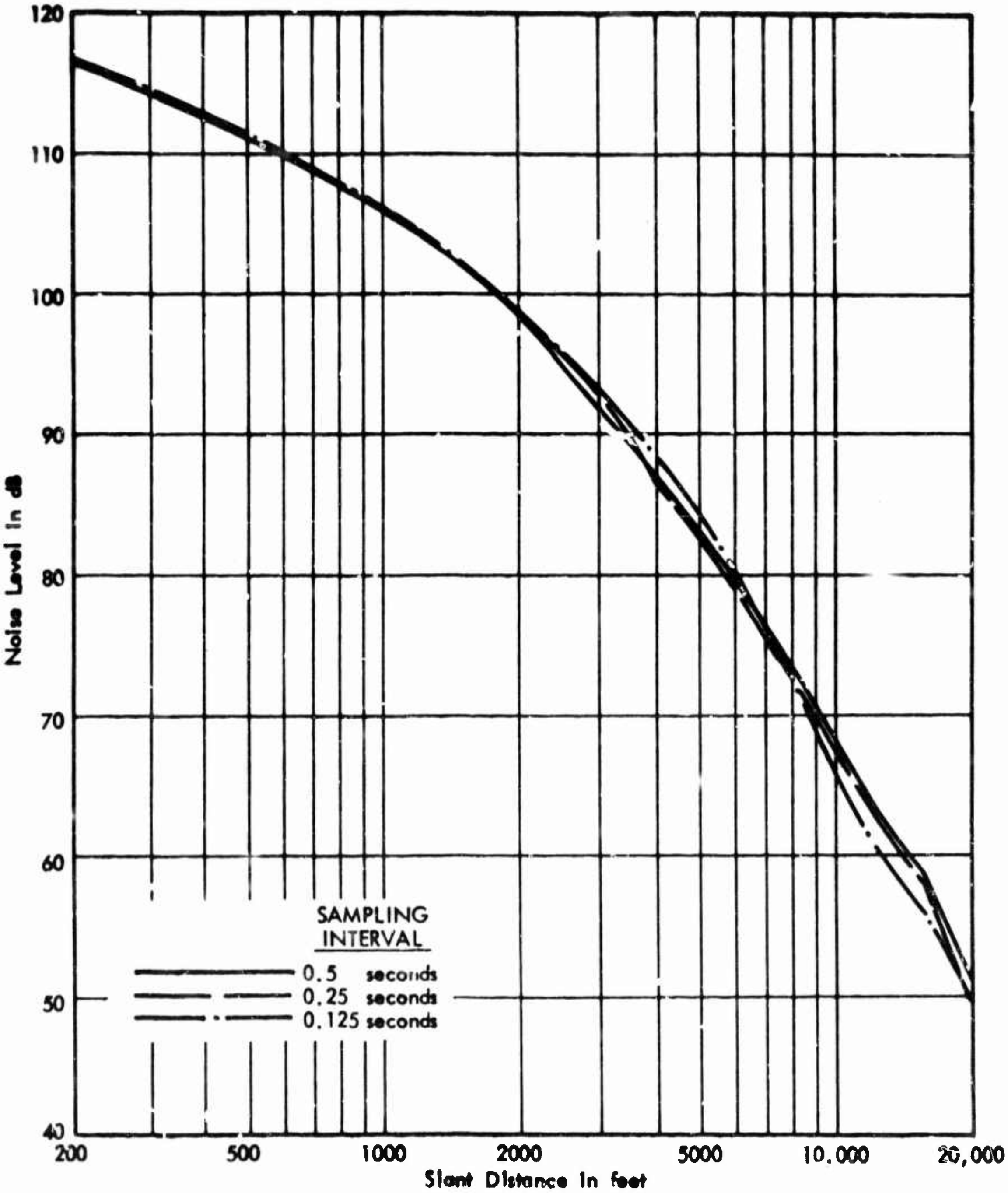


FIGURE C-23. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-03)

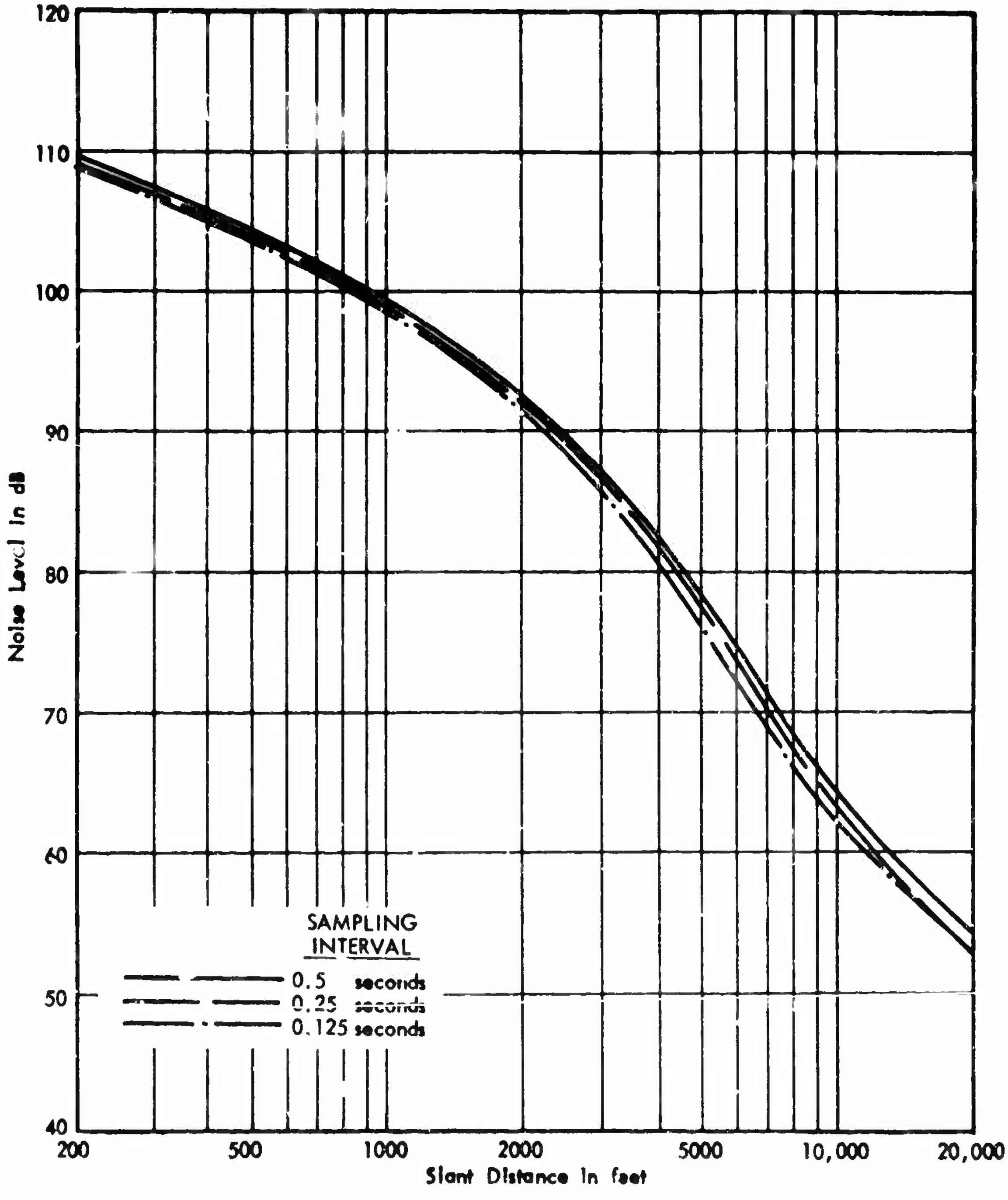


FIGURE C-24. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT SAMPLING INTERVALS - C135B, CRUISE THRUST, 400 FEET, 300 KNOTS (RUN 72-025-006-03)

APPENDIX D

SUPPLYING MISSING SPECTRUM LEVELS FOR PNL AND EPNL CALCULATIONS

A. INTRODUCTION

The processing of recorded field noise data often results in spectra with one or more "missing" one-third octave band levels. Ambient or system noise, dynamic range limitations or ground reflection effects result in loss of parts of spectra, typically beginning with the highest frequency bands. The resulting loss of one-third octave band information results in errors in calculated values of PNL, PNLT, A-level, etc. Past experience has generally shown that the omission of one or two band levels introduces little error. However, little information is available as to the degree of degradation in spectrum information which can be tolerated before sizable errors are introduced.

This appendix discusses the probable magnitude of errors due to missing band levels and presents a simple algorithm for supplying the missing levels which reduces the likelihood of sizable errors.

With parts of the spectrum missing, calculated PNL or A-level values are lower than the "actual" levels which would have been obtained had all the noise level information been available. Missing bands can also result in false "tone corrections" which in turn may result in occasional calculated PNLT values which are higher than the "actual" values. Typically, the number of missing bands will be minimal near the peak of an aircraft flyover signal but will increase as noise levels fall off. As a result, the calculated flyover durations may tend to be shorter than actual, resulting in possible under-estimation of integrated noise measures such as the EPNL and SEL.

B. APPROACH

Analysis was based upon consideration of the effects of missing data for two basic noise spectrum families -- those produced by an F-100 takeoff and a 727 approach. One-third octave band spectra for each of the two families were generated at a number of distances; spectra at distances of 400, 1000 and 5000 feet were selected for study. These spectra are shown in Figure D-1.

For each of these six basic spectra, sets of spectra with missing bands were generated as follows:

1. For each of the six basic spectra, the dynamic range was systematically reduced by 5 dB steps. This resulted in successive omission of increasing numbers of frequency bands. PNL, PNLT and A-levels were then calculated from the remaining bands (i.e., the missing bands were simply omitted from the resulting calculations).

2. The spectra were systematically reduced as in (1). However, "missing" band levels were supplied by the following simple rules:

   (a) For missing high frequency band levels, generate levels by extrapolating the slope of the two preceding (lower) bands, provided the change in slope is 6 dB or greater. If the slope is less than 6 dB, assume an arbitrary decrease of 6 dB per one third octave band.

   (b) For missing band levels where levels are reported at both higher or lower frequencies, generate the missing band levels by interpolation between the nearest adjacent band levels.

(c) For missing low frequency bands, set the levels equal to the nearest band level.

C. RESULTS

The calculations were analyzed by comparing the PNL and PNLT values with those for the original spectra with no missing bands. Results were plotted in terms of the total dynamic range of the signal with missing bands and in terms of the number of bands actually used in the calculations (excluding bands for which levels were assumed). Results, plotted in terms of number of bands, are shown in Figures D-2, D-3 and D-4.

In terms of dynamic range, and with bands simply omitted, little error in PNL (less than 1 dB) resulted until the dynamic range was reduced to 20 dB or less. With the missing bands supplied by the logic indicated above, the dynamic range could typically be reduced to 10 dB or less; however, some of the fan spectra showed errors in excess of 1 dB (calculated values higher than actual) when the dynamic range decreased to 18 dB or less.

Analyzed in terms of number of bands used in calculations, the errors due to missing bands were less than 1 dB until the number of bands was reduced to 18 or less as shown in Figure D-2. With the missing bands filled in by the logic described above, the number of bands could be reduced to 10 without an error of more than 1 dB. This is illustrated in the upper portion of Figure D-4.

For the 727 approach case, PNLT values were irregular as bands were omitted, with wide variations observed as the number of bands decreased below 22. See Figure D-3. The rather erratic results obtained from this analysis are to be expected because of the logic currently employed in the tone corrections procedures specified under FAR 36. However, with the missing bands supplied in accordance with the logic used above, the PNLT values changed smoothly and showed errors of less than 1 dB until the number of bands was reduced to 6 or less, as illustrated in the lower portion of Figure D-4.

D. RECOMMENDATIONS

Based on the results described above, the following recommendations are made.

1. Employ the rules described under (B) for supplying missing band level information for both flyover and ground runup noise data.

2. On plots showing the time history of flyover noise levels, or on tabulations of one-third octave band spectra, flag the spectra (or times) where spectra having less than 20 bands were measured.

3. Do not calculate PNL, PNLT, A-levels or other measures for spectra where less than 10 bands were measured.

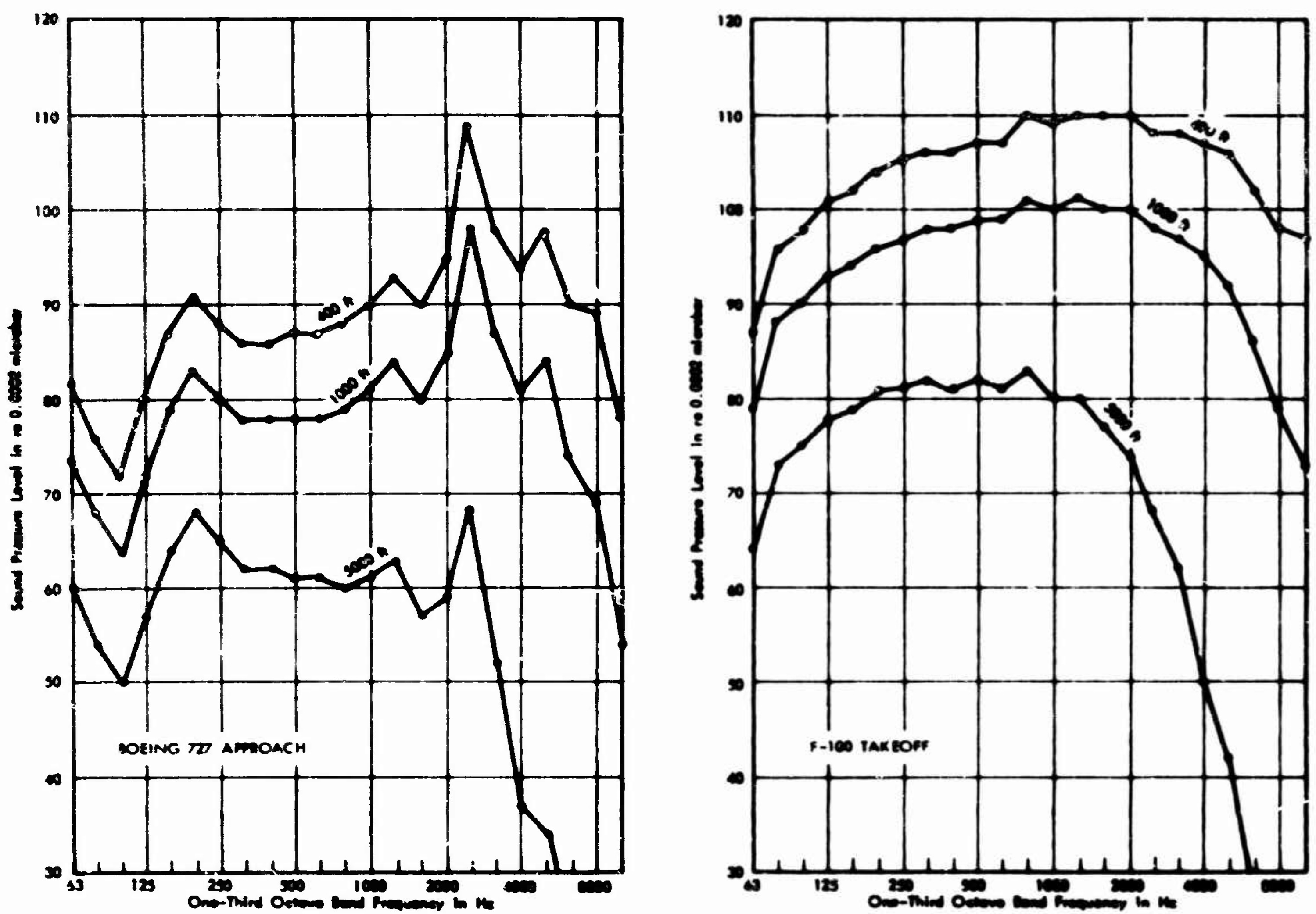


FIGURE D-1. NOISE SPECTRA FOR MISSING BAND LEVEL CALCULATIONS

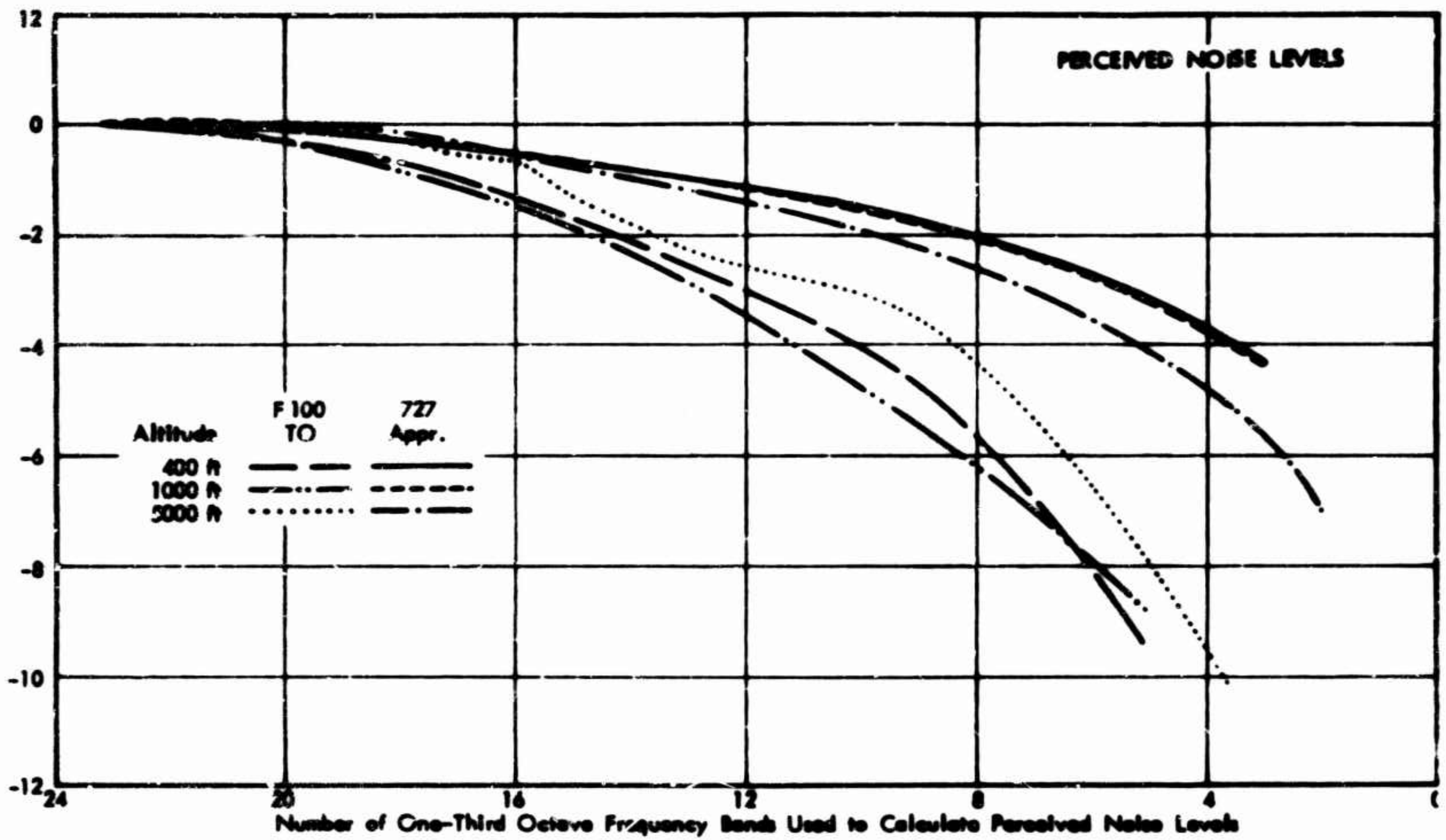


FIGURE D-2. DIFFERENCE IN PERCEIVED NOISE LEVELS CALCULATED WITH FULL AND TRUNCATED SPECTRA - MISSING BAND LEVELS SIMPLY OMITTED FROM CALCULATIONS

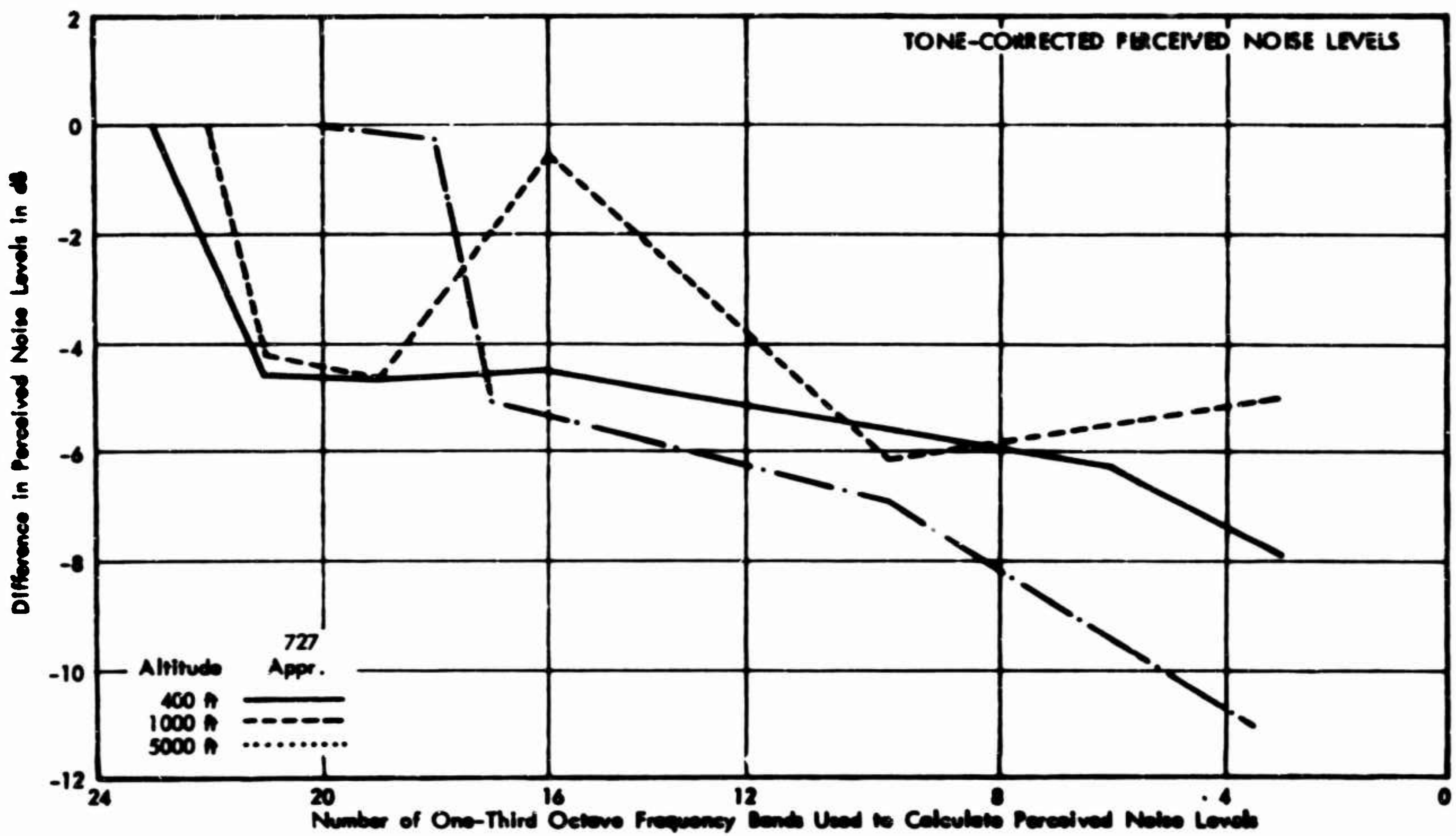


FIGURE D-3. DIFFERENCES IN TONE-CORRECTED PERCEIVED NOISE LEVELS CALCULATED WITH FULL AND TRUNCATED SPECTRA - MISSING BAND LEVELS SIMPLY OMITTED FROM CALCULATIONS

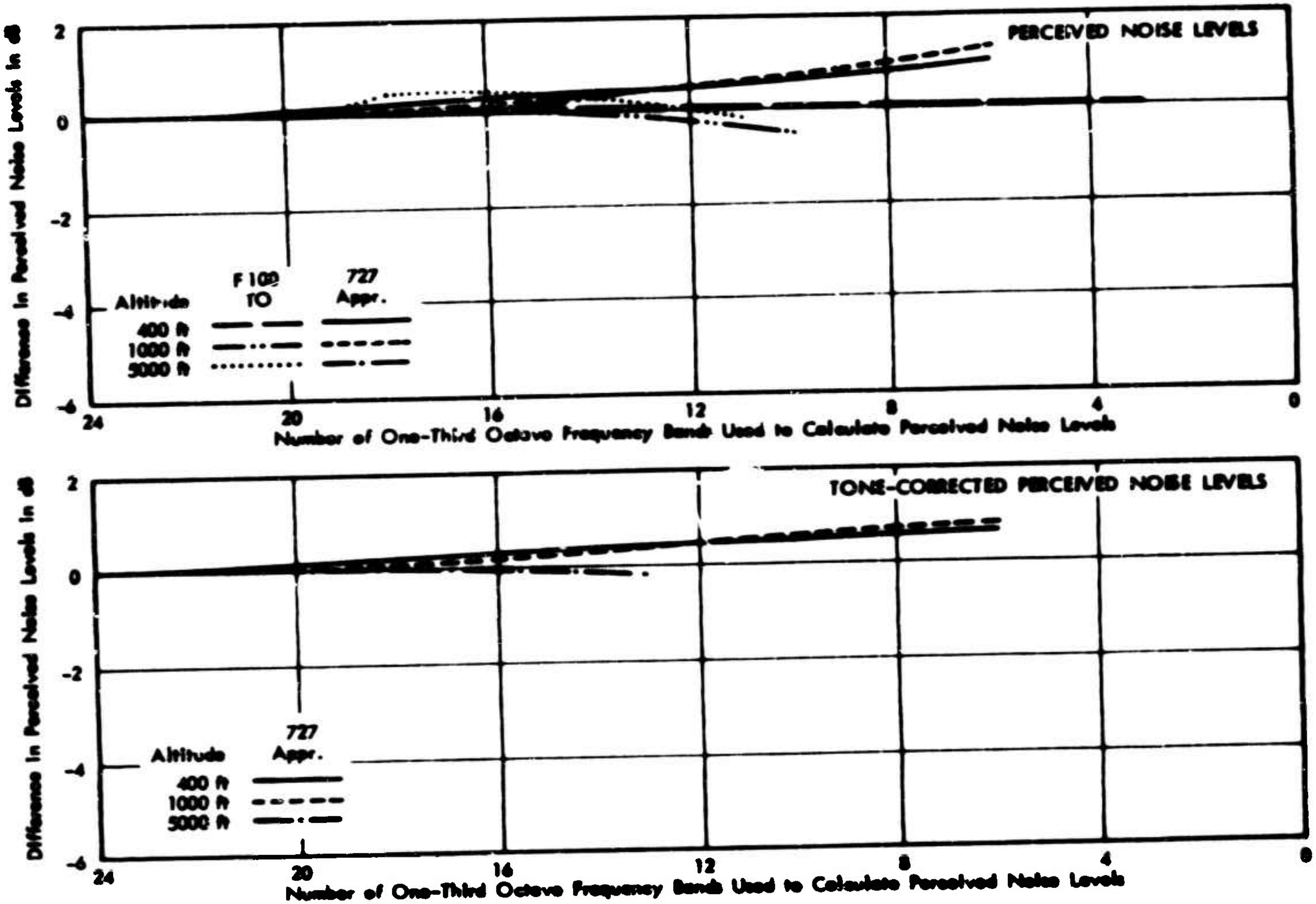


FIGURE D-4. DIFFERENCE IN PERCEIVED NOISE LEVELS CALCULATED WITH FULL AND TRUNCATED SPECTRA - MISSING BAND LEVELS SUPPLIED BY ALGORITHM

APPENDIX E

CHOICE OF ANGLES AND NOISE SPECTRUM FOR EXTRAPOLATING NOISE LEVELS TO DIFFERENT DISTANCES

A. DISCUSSION

The simple analytic model employed for estimating EPNL values at distances other than measured assumes that at the reference distance;

$$EPNL = PNLT(\theta) + D$$

where θ is the angle of maximum radiation and PNLT is calculated from the spectrum at θ. For other distances it is assumed that the EPNL varies due to.

1. Changes in PNLT, where PNLT is calculated from a one-third octave band spectrum which is derived from the reference spectra after inverse square adjustments for distance and adjustments for air absorption.

2. Changes in D which are proportional to 10 times the logarithm of the ratios of the air speeds, and the inverse ratios of distance.

A question arises as the criterion to be used for choosing θ, and, in turn, the spectrum corresponding to θ. An initial choice might be on a basis of the maximum PNLT value observed during the flyover. However, one might also consider choices based on the maximum PNL, A-level or D-level. For aircraft noise sources where the directional characteristics show a pronounced single lobe (in contrast to multiple lobes) and where the shape of the noise spectra does not vary drastically at different angles, one will generally find relatively good agreement in choice of maximum angle for the several noise levels. However, where directional patterns show more than one lobe, and particularly where spectrum shape shows large differences with radiation angle, there can be sizable differences between the angles chosen on basis of PNLT, PNL or other noise measures which can result in significant differences in noise level projections.

Several kinds of problems may arise:

1. With more than one lobe, the maximum angle may be dependent on the choice of the noise measure, leading to widely different choices of angles and spectra.

2. Where there are two or more lobes, maximum angles may vary sizably from run to run. At one time, a forward lobe might be chosen from the flyover time history; on another run, the second lobe might be the maximum.

Typically, these problems are most likely to occur at approach or cruise thrusts for turbojet and turbofan aircraft. They are both evident in sets of Air Force level flight flyover data for the C-135A aircraft at approach and cruise power. As an example, Figure E-1 shows the PNLT time histories for eight approach power runs. In the figure, the time histories have been aligned so that the maximum values for the second lobe coincide. (The time histories are displaced vertically so that there is a 10 dB displacement between the maxima of the second lobes.) For three of the eight runs, the PNLTM value is due to the forward lobe, while in the remaining cases, the rear lobe dominates.

Two other factors should also be considered: First, the current method for calculating the tone correction for the PNLT values sometimes give erratic results which are tied to particular spectrum details. Occasionally, this may introduce an error in selecting the maximum angle, θ. A more significant problem arises from the strong compressor or fan components found in the vicinity of 2,000 Hz for many current jet aircraft. When there is a strong tone component the spectrum selected on the basis of PNLT may have relatively low sound pressure levels in the middle and lower frequency bands. Thus, when this spectrum is extrapolated to large distances, the resulting noise level versus distance curves will show a high rate of change of noise levels with distance due to the rapid attenuation of the strong tone component. At large distances, the calculated noise levels may underestimate the jet noise contributions.

B. DATA ANALYSES

To examine the effects of using different criteria in choosing angles and corresponding spectra, noise level versus distance curves were generated from sets of flyover data for the C-135A at approach and cruise thrusts using different criteria in selecting θ. For each run in the two sets of data, θ values (and spectra) were selected for the maximum PNLT, maximum PNL, maximum A-level and maximum D-level.* In addition, one run which showed a large time difference between maxima selected by differing criteria was analyzed separately.

For the 12 sets of approach data, normalized to 400 feet, the average spectra selected on the basis of the different criteria are shown in Figure E-2. There is a relatively large difference between the spectrum selected on the basis of PNLT, and the remaining spectra. However, the spectra selected on the basis of either PNL, A-level or D-level maxima show only small differences.

*For the twelve sets of approach data, the θ values selected on the basis of PNLT or PNL were the same in four runs, and differed in eight. For the eight sets of cruise data, the θ values were the same for three runs, and differed in five.

Table E-1 shows the average value of θ, and the standard deviation for the average value, for the different criteria. For both the cruise and approach data, there is a relatively large difference in θ between the PNLTM criteria and the others. The standard deviation for the PNLTM criteria is large for the approach data, but relatively small for the cruise data.

From the spectra and θ values of Figure E-2 and Table E-I, noise level versus distance curves were generated for PNLT, PNL, A-level, EPNL and SEL. The corresponding plots are shown in Figures E-3 through E-7. In each of the figures, one will note that the noise level values chosen on the basis of the PNLT maxima drop off more rapidly with distance and, at large distances, fall well below the noise levels projected on the basis of the other choices of θ. Figure E-8 shows the differences between projected noise levels chosen on the basis of PNLTM or PNLM criteria at four distances: 400, 1000, 4000, and 10,000 feet. Typically, the choice based on PNLT criteria results in slightly higher PNLT or EPNL values at 400 feet. But, for other measures at any distance, or for EPNL and PNLT at distances beyond 1000 feet, noise levels projected on the basis of PNLT criteria are lower than those based on PNL criteria.

Results of a similar analysis for the eight sets of C-135A data taken at cruise power are shown also in Figures E-9 through E-14. Spectra are shown in Figures E-9 and corresponding plots of noise level versus distance are shown in Figures E-10 through E-14. Figure E-15, in a presentation similar to Figure E-8, compares the differences in noise levels depending on choice of PNLTM and PNLM criteria. The trends for the cruise data are the same as for the approach data, except that the differences between noise levels based on the PNLTM criteria and those for the other criteria are even more pronounced at large distances.

From the sets of C-135A approach data, a "worst case" single run was analyzed, based upon the selection of the run which showed the greatest time difference between maxima selected by different criteria. (The information presented in the previous figures is based upon averaging eight or twelve sets of data.)

Figure E-16 shows the spectra for the different θ values, and Figures E-17 through E-21 show the noise level versus distance curves. The difference between noise level projections based on PNLTM and other criteria are larger for this "worst case" than for the averaged data. Figure E-20, for example, shows differences between EPNL values of about 17 dB at 10,000 feet.

It should be emphasized that significant differences in noise level projections based on differences in selecting θ will not occur often for most current jet aircraft, and would rarely, if ever, occur at takeoff thrust. For example, examination of 16 sets of C-135A takeoff data (12 dry and 4 wet runs) showed that the times of maximum (PNLT, PNL, A-level or D-level) coincides for 14 of the 16 runs, and differed by at most 0.5 seconds in only two runs.

C. RECOMMENDATIONS

On the basis of the above, it is recommended that PNLM be used as the basis for choosing θ and the corresponding spectra for estimating noise levels at other distances. This recommendation is based on the fact that use of the PNL as the basis for choosing the maxima directivity angle, rather than PNLT, will result in conservative (i.e., higher) estimates of noise levels at large distances, and will reduce the risks of serious underestimation of noise levels for planning purposes.

It is further recommended that the angle and spectra based on PNLM also be used for estimating A-level and SEL values. Study of the figures presented in this appendix will show that the differences in noise level projections between those based on PNL or A-level criteria are typically very small, hence the computational complexities of dual criteria for selecting one or two spectra and angles for noise level projections does not seem warranted at this time.

TABLE E-I

THETA VALUES FOR DIFFERENT CRITERIA -- C-135A APPROACH AND CRUISE DATA

Noise Criteria	Approach θ	Approach s	Cruise θ	Cruise s
PNLTM	60.0°	31.0°	30.0°	8.0°
PNLM	96.5°	11.5°	54.0°	18.5°
ALM	98.0°	13.0°	69.0°	13.5°
DLM	91.5°	22.5°	62.5°	20.0°

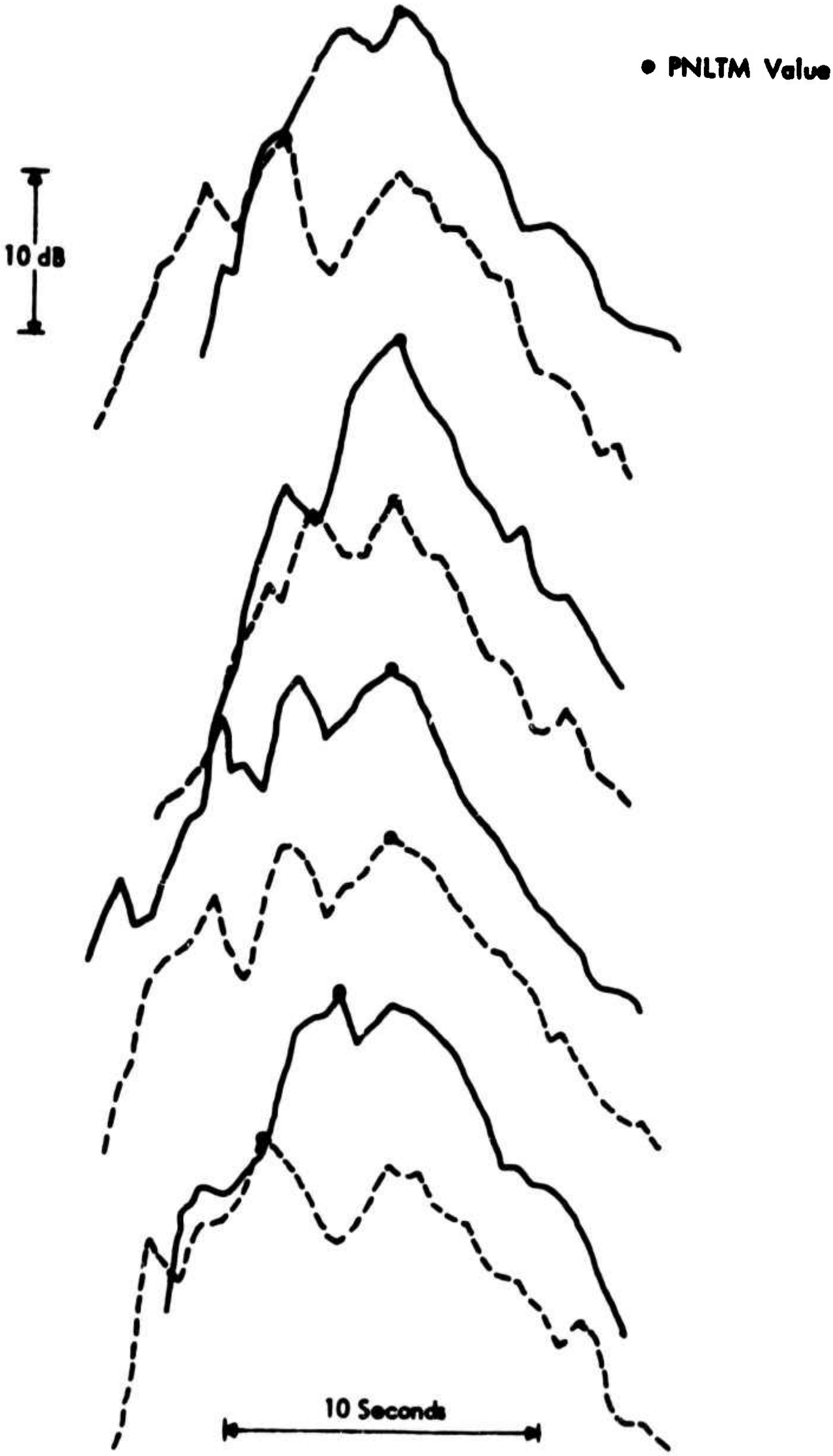


FIGURE E-1. COMPARISON OF PNLT TIME HISTORIES - C135A, APPROACH THRUST, 400 FEET, 300 KNOTS

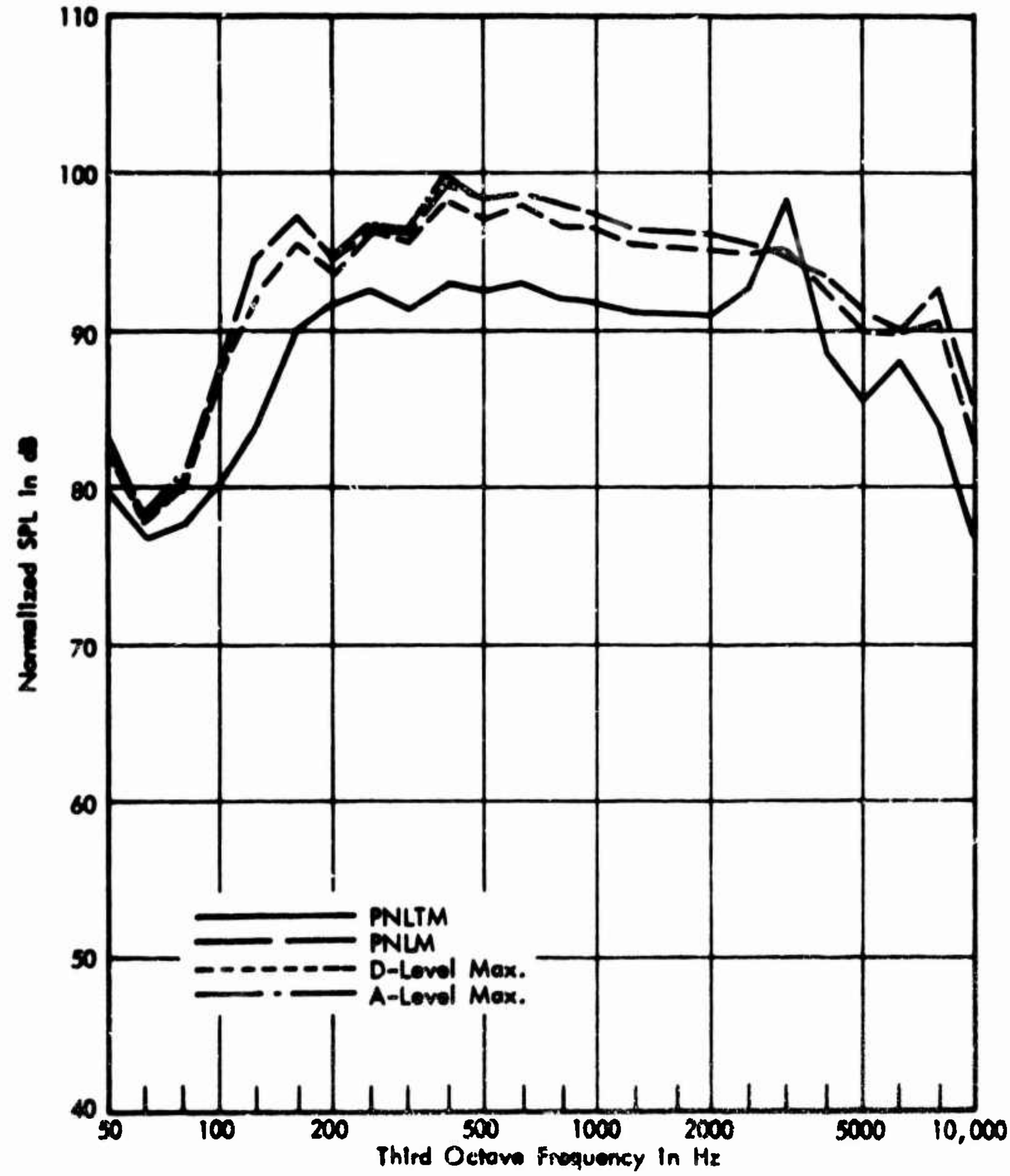


FIGURE E-2. NORMALIZED FLYOVER NOISE SPECTRA AT θ - C135A, APPROACH THRUST, 400 FEET, 160 KNOTS (12 RUNS)

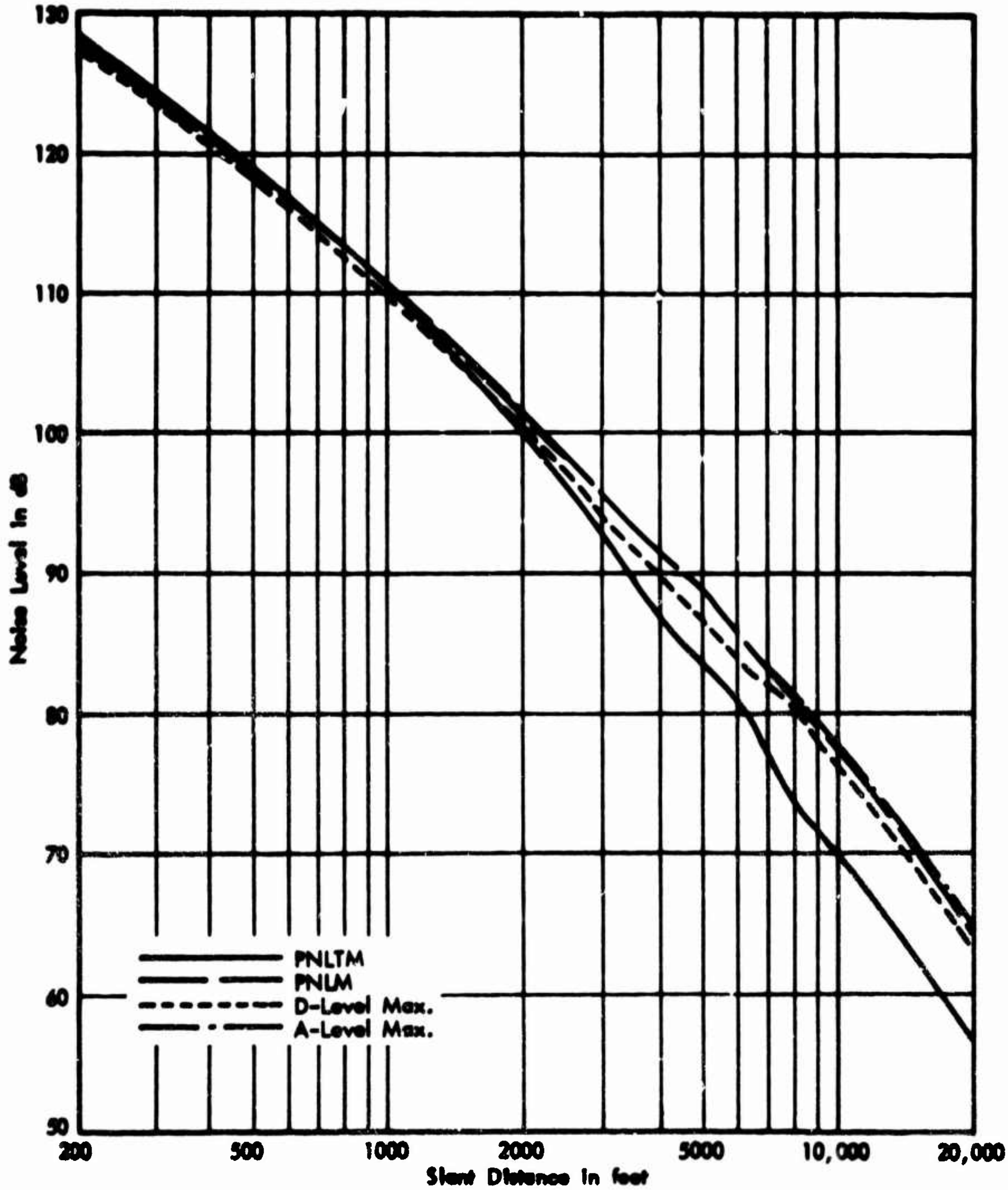


FIGURE E-3. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS

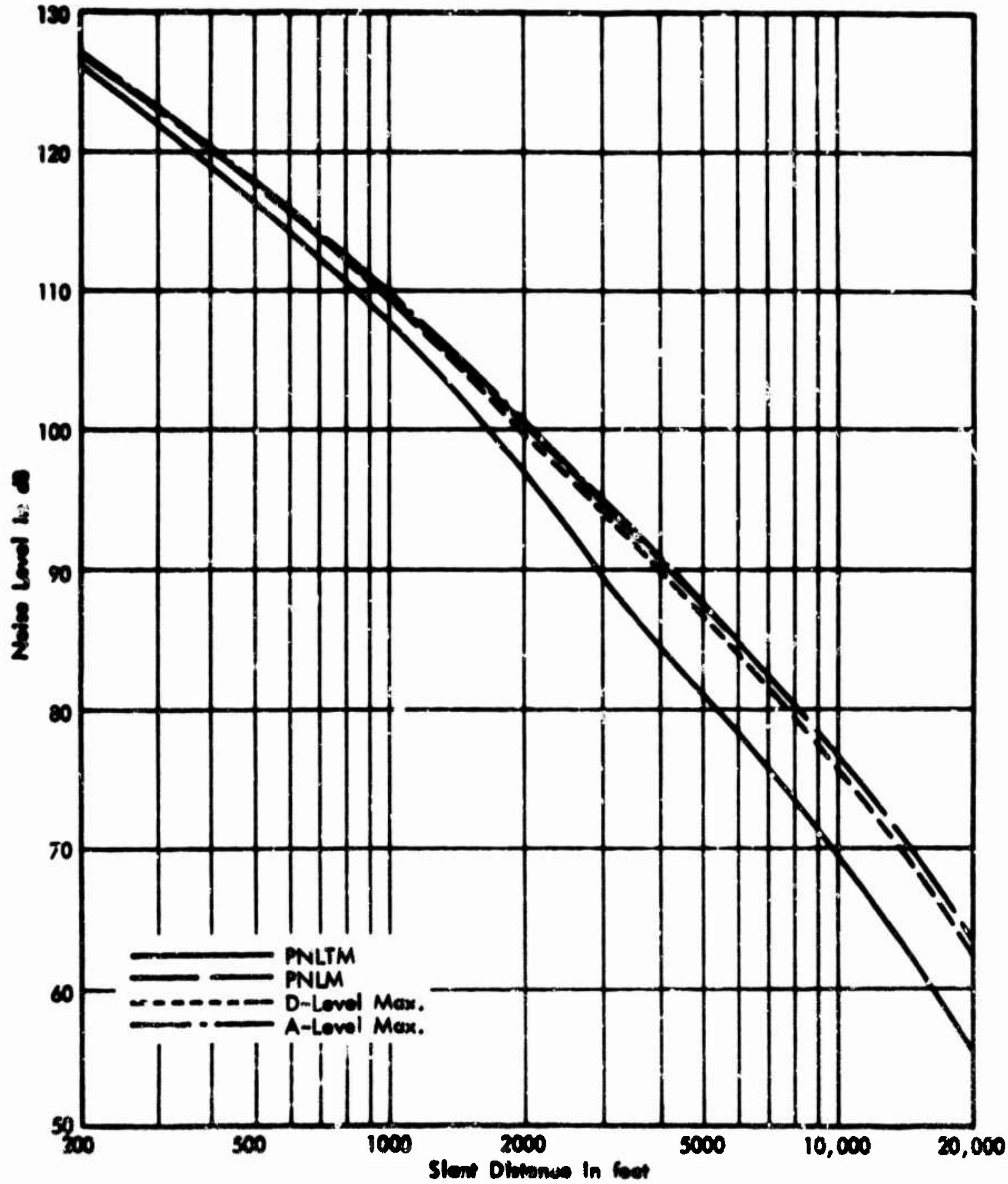


FIGURE E-4. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS

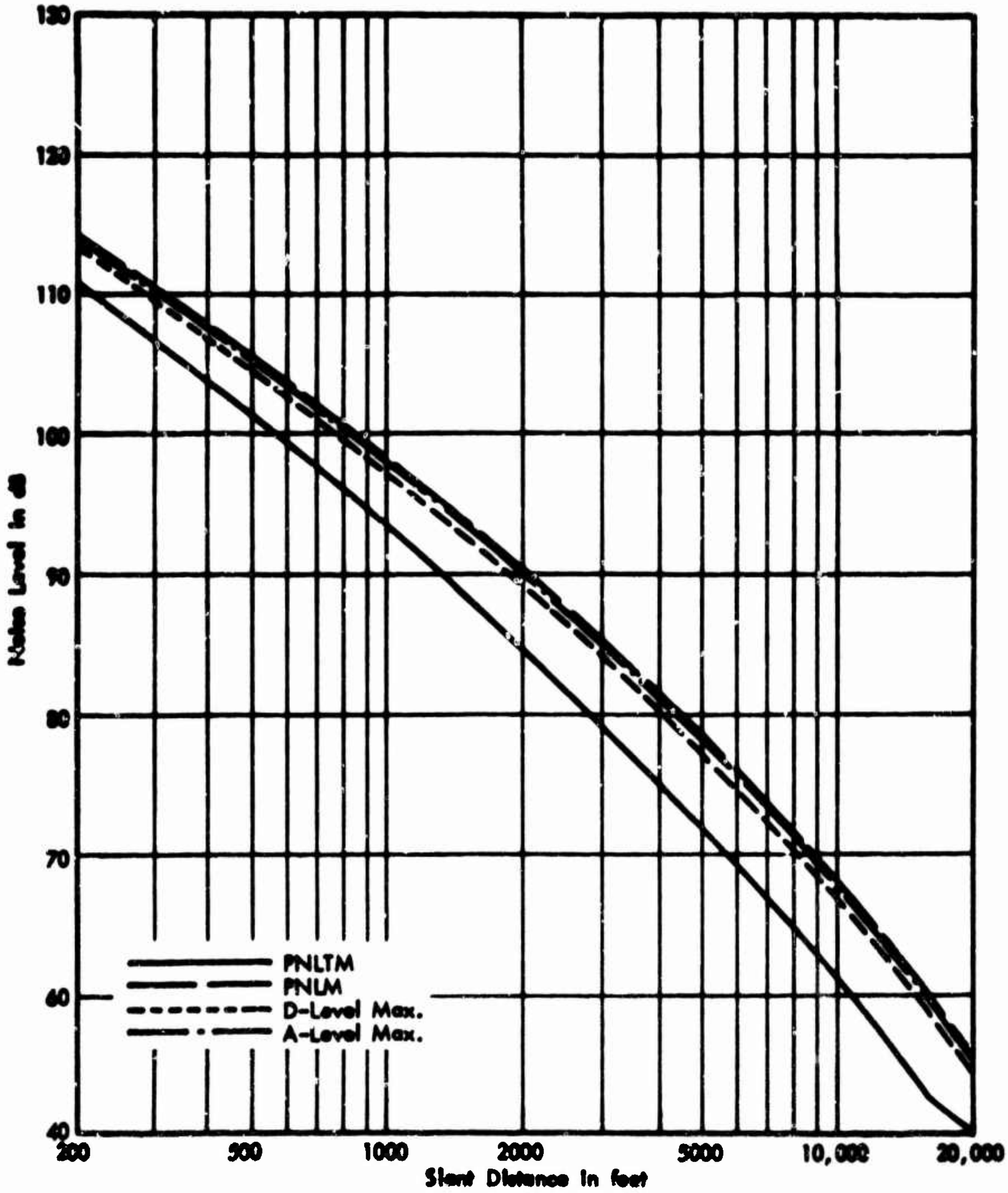


FIGURE E-5. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA-C135A, APPROACH THRUST, 160 KNOTS

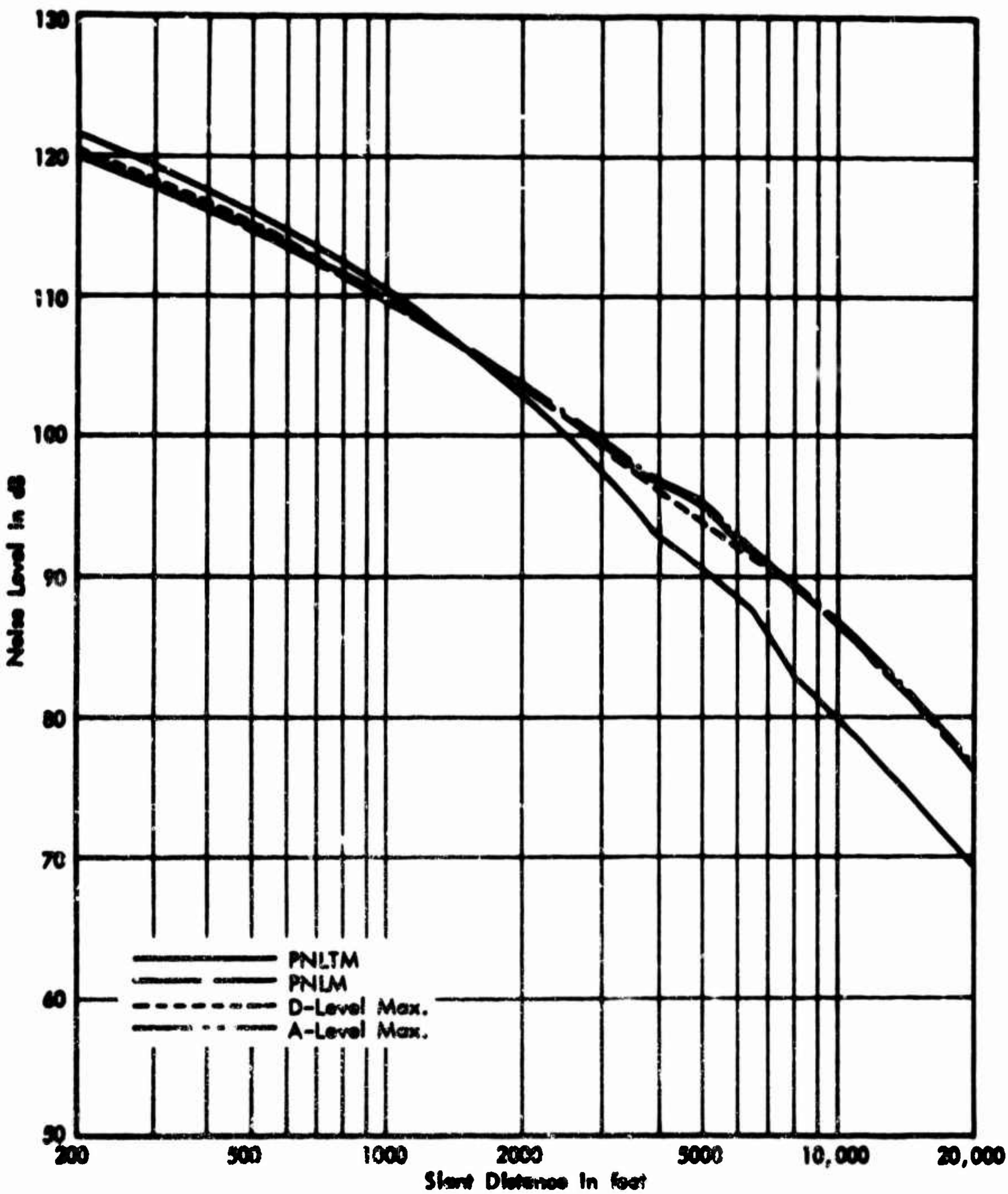


FIGURE E-6. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT # CRITERIA - C135A, APPROACH THRUST, 160 KNOTS

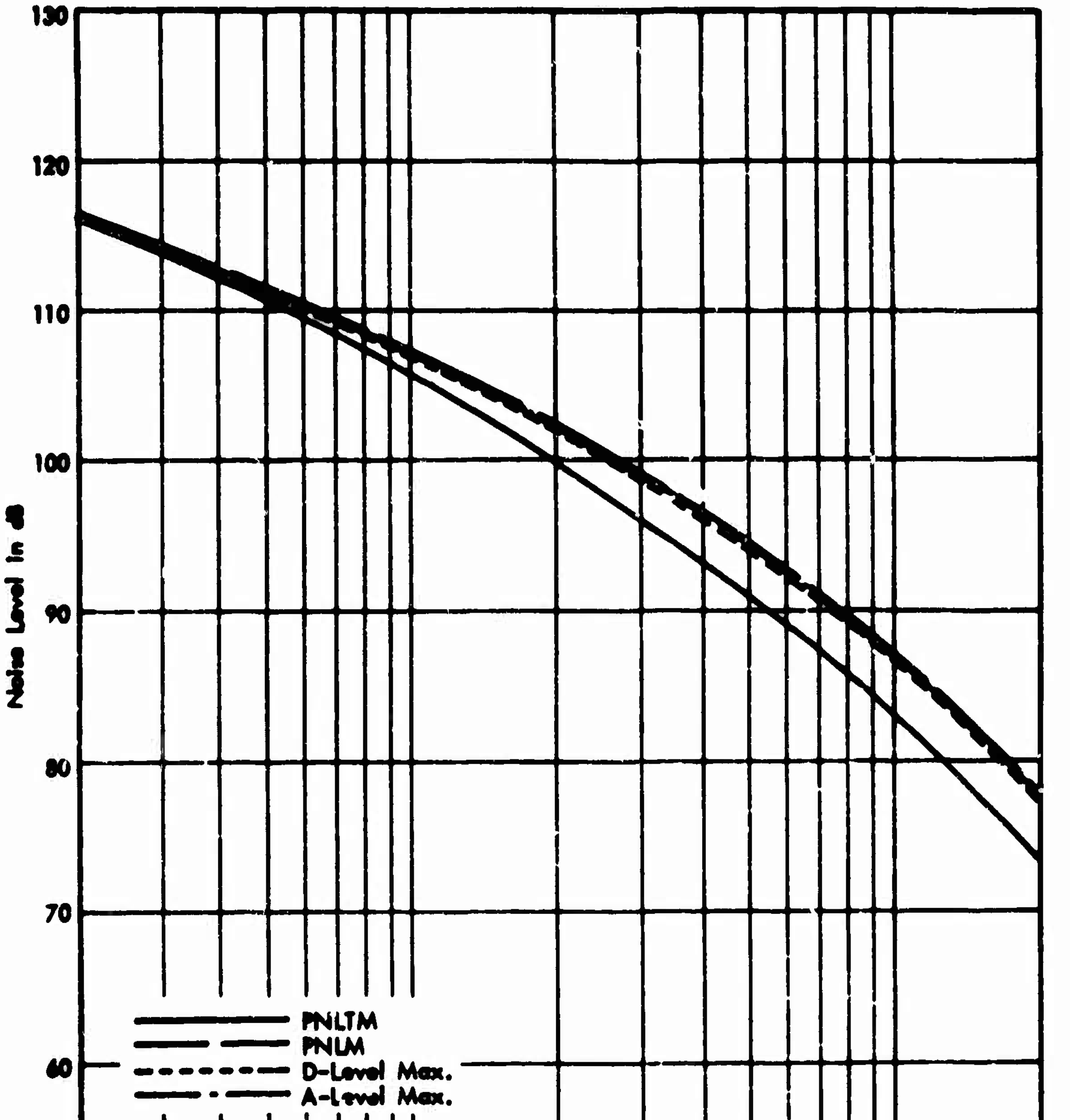


FIGURE E-7. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS

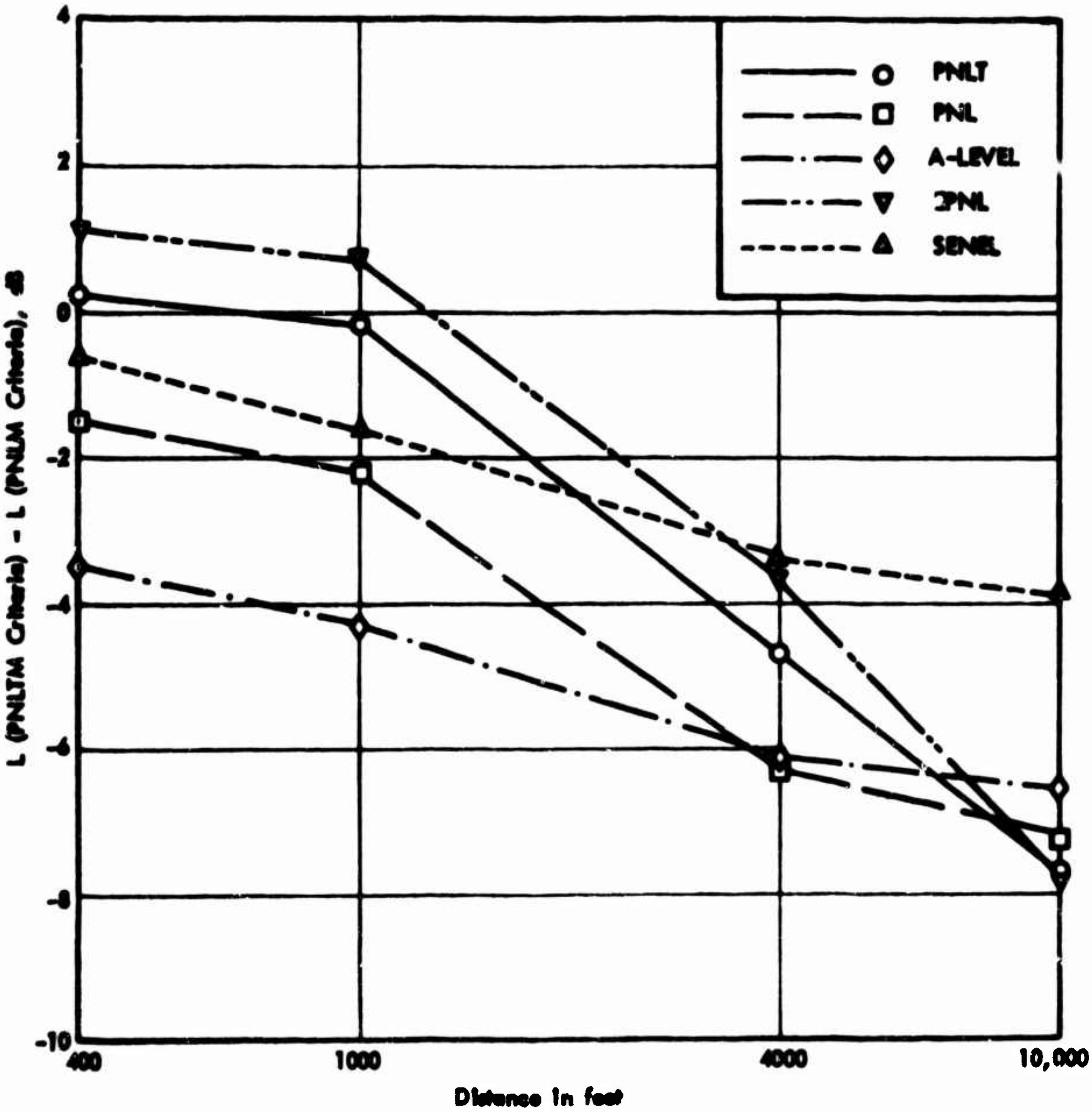


FIGURE E-8. DIFFERENCES IN NOISE LEVELS AT VARIOUS DISTANCES FOR NOISE CURVES SELECTED ON BASIS OF PNLTM OR PNLM CRITERIA - C135A AIRCRAFT, APPROACH THRUST, 160 KNOTS

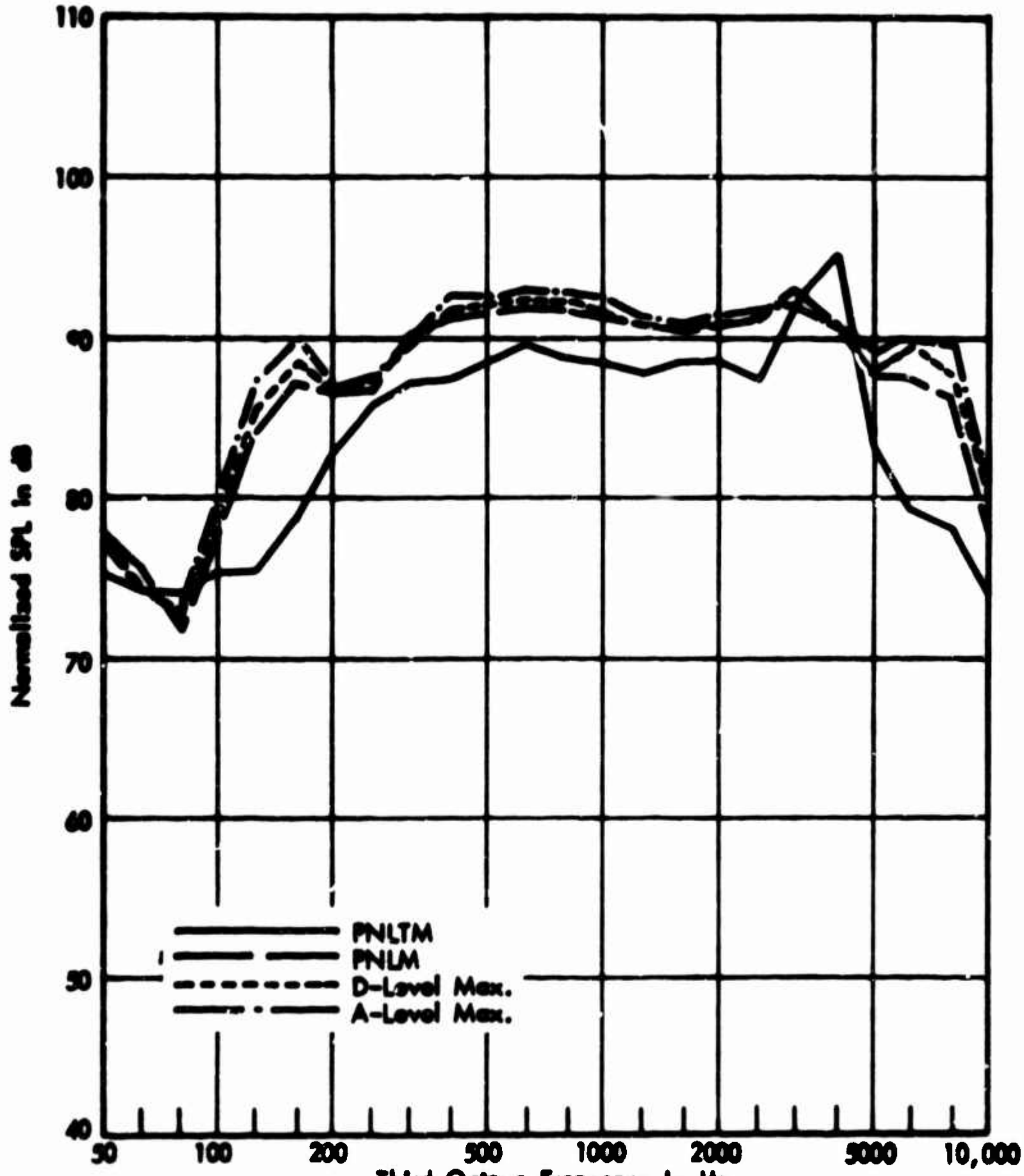


FIGURE E-9. NORMALIZED FLYOVER NOISE SPECTRA AT θ - C135A, CRUISE THRUST, 400 FEET, 300 KNOTS (8 RUNS)

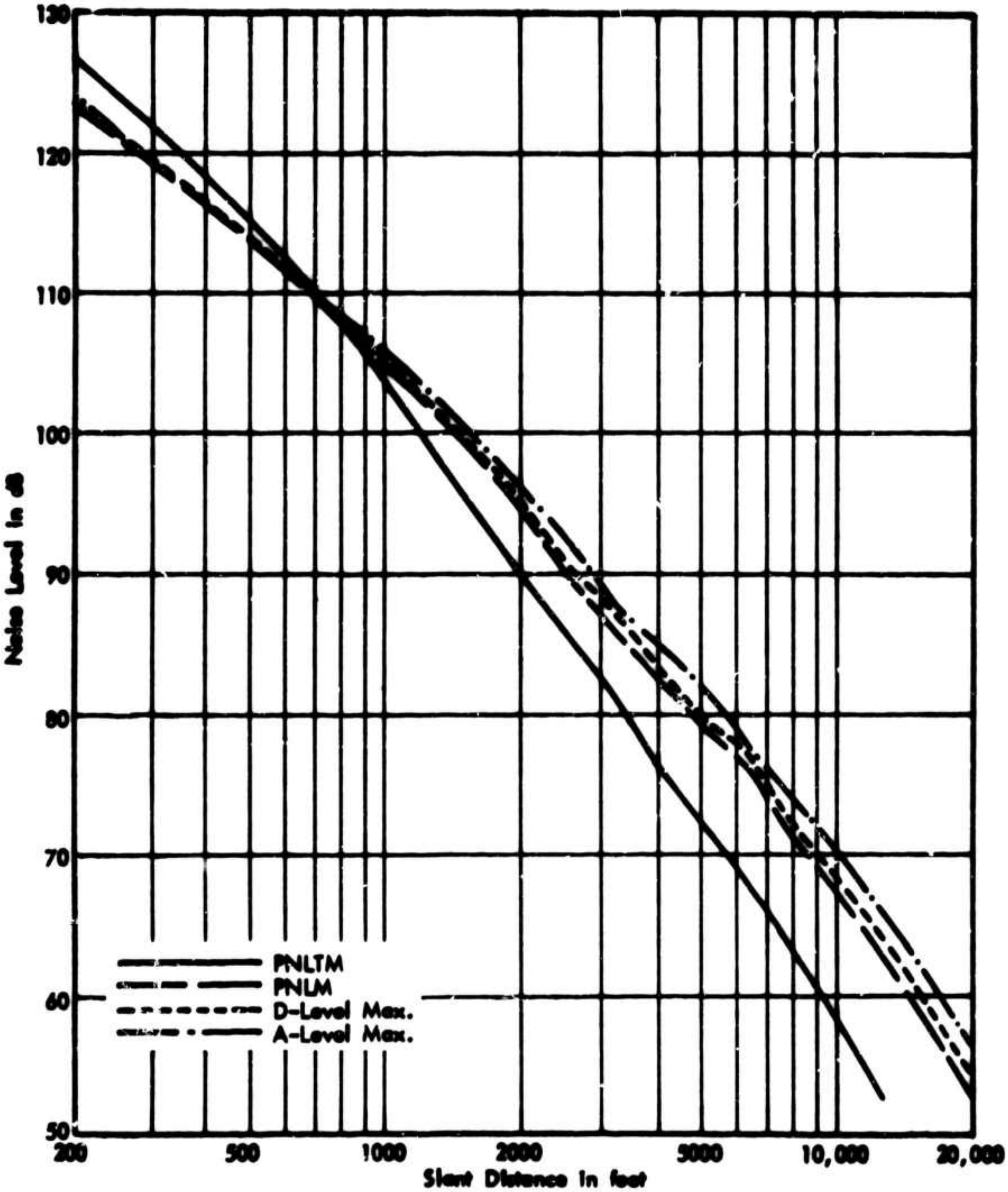


FIGURE E-10. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A CRUISE THRUST, 300 KNOTS

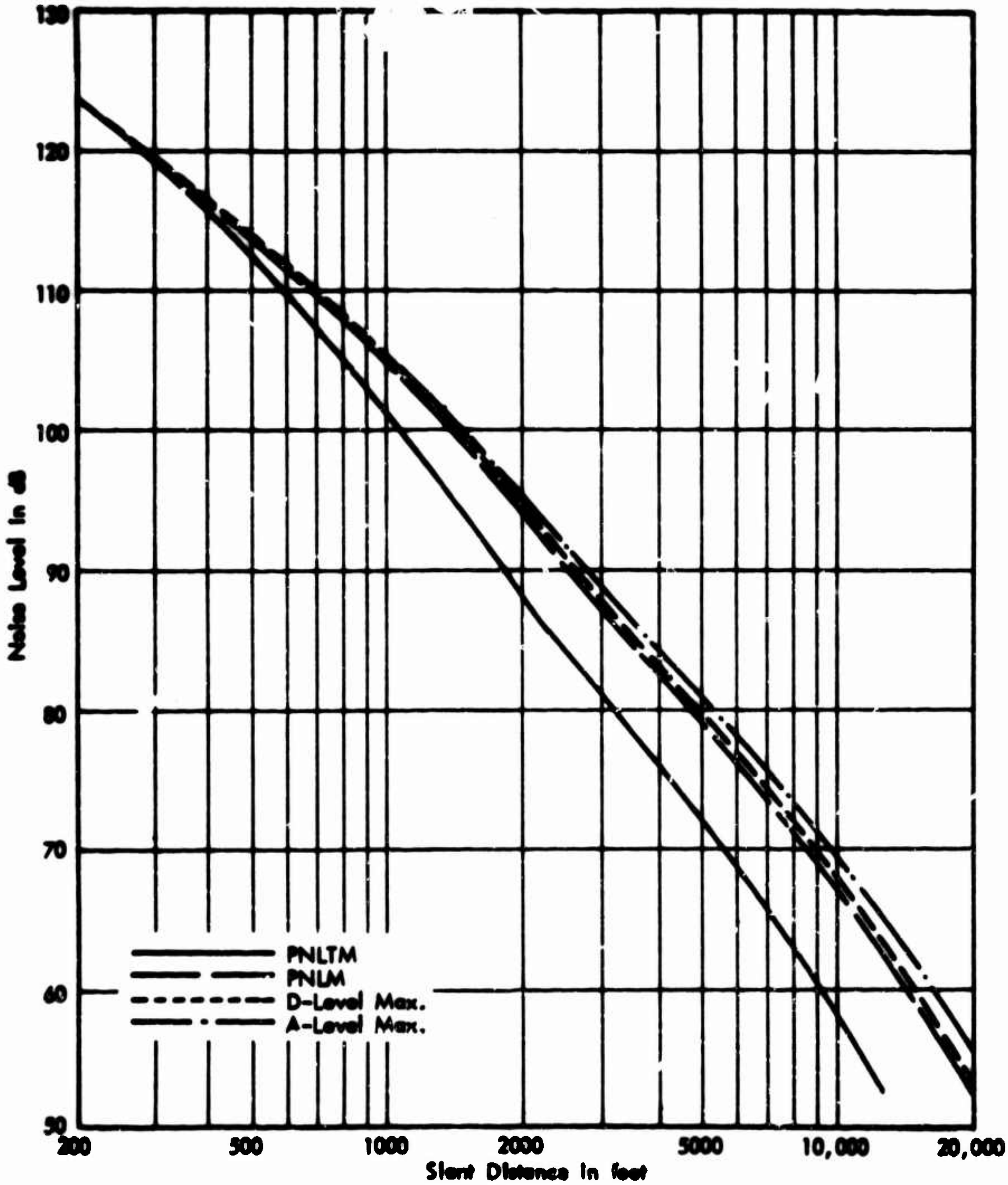


FIGURE E-11. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A CRUISE THRUST, 300 KNOTS

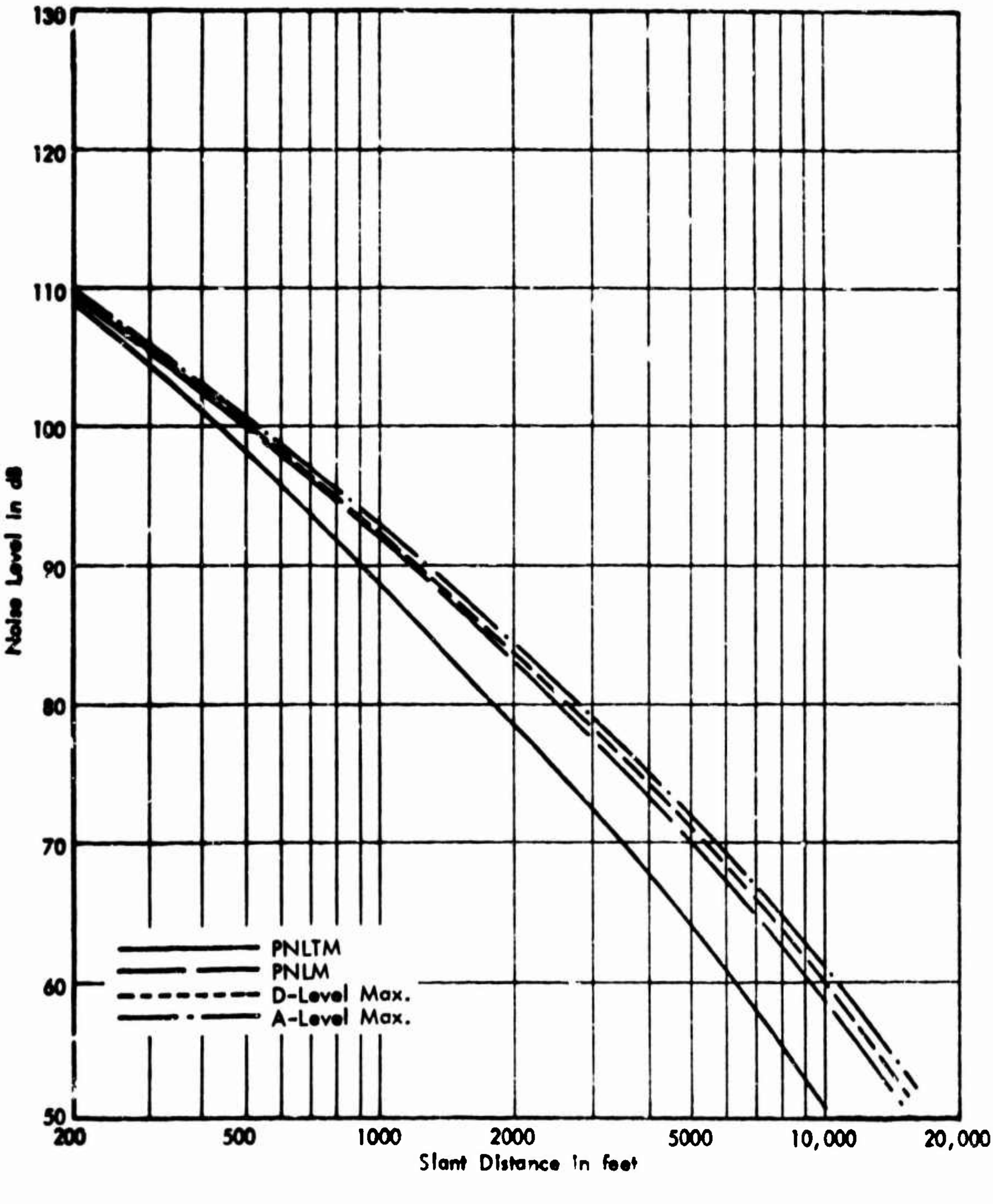


FIGURE E-12. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT CRITERIA - C135A CRUISE THRUST, 300 KNOTS

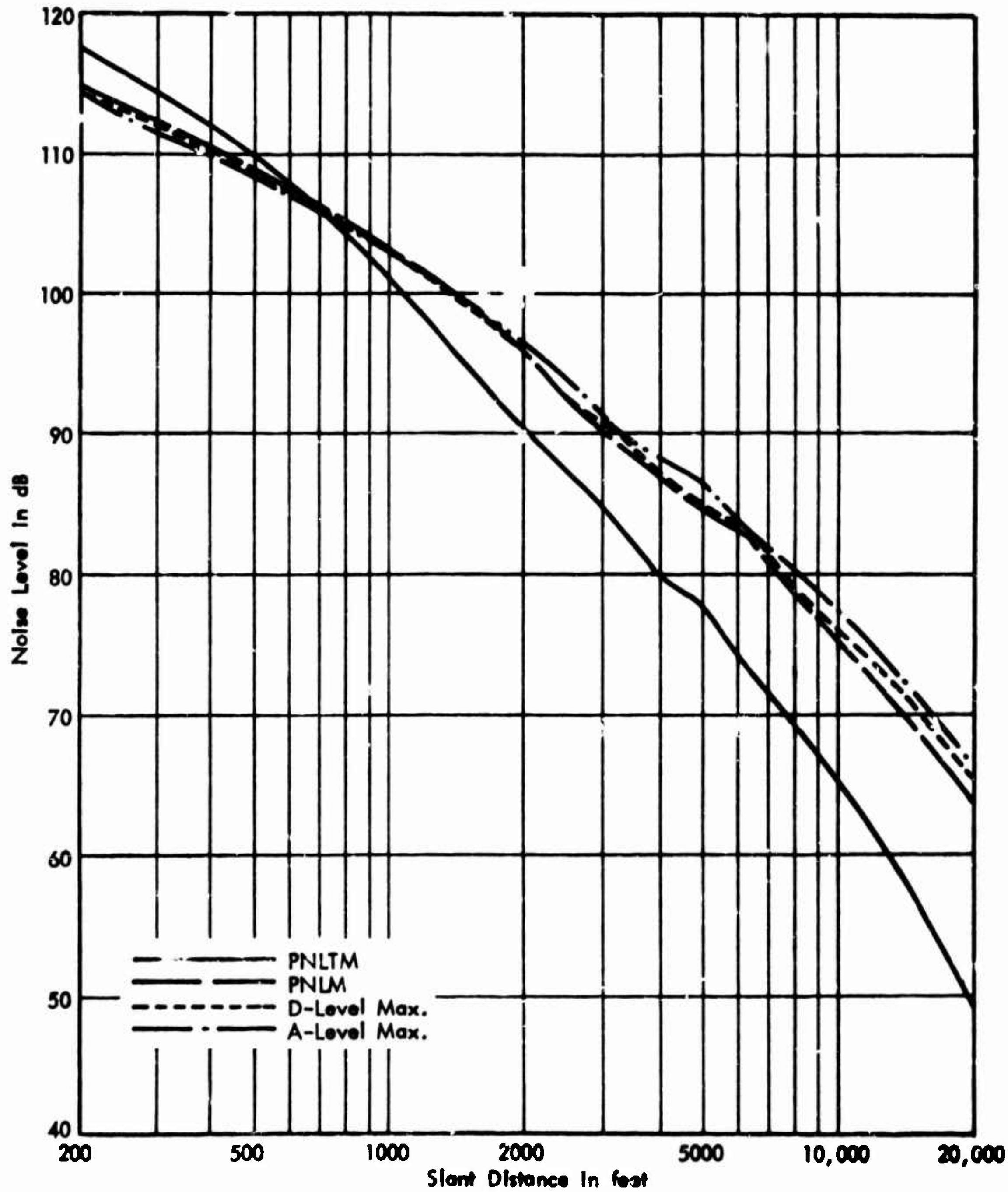


FIGURE E-13. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A CRUISE THRUST, 300 KNOTS

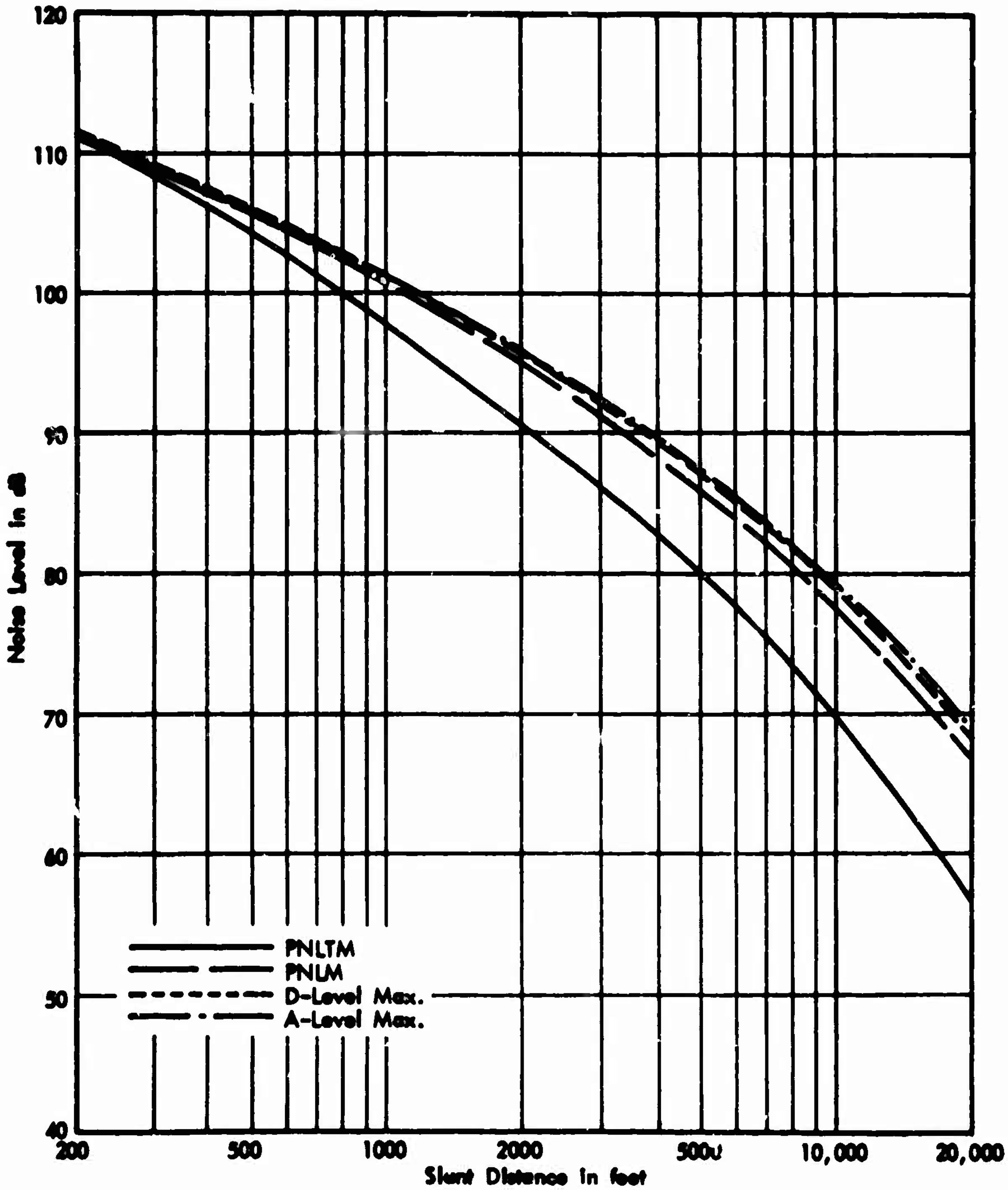


FIGURE E-14. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A CRUISE THRUST, 300 KNOTS

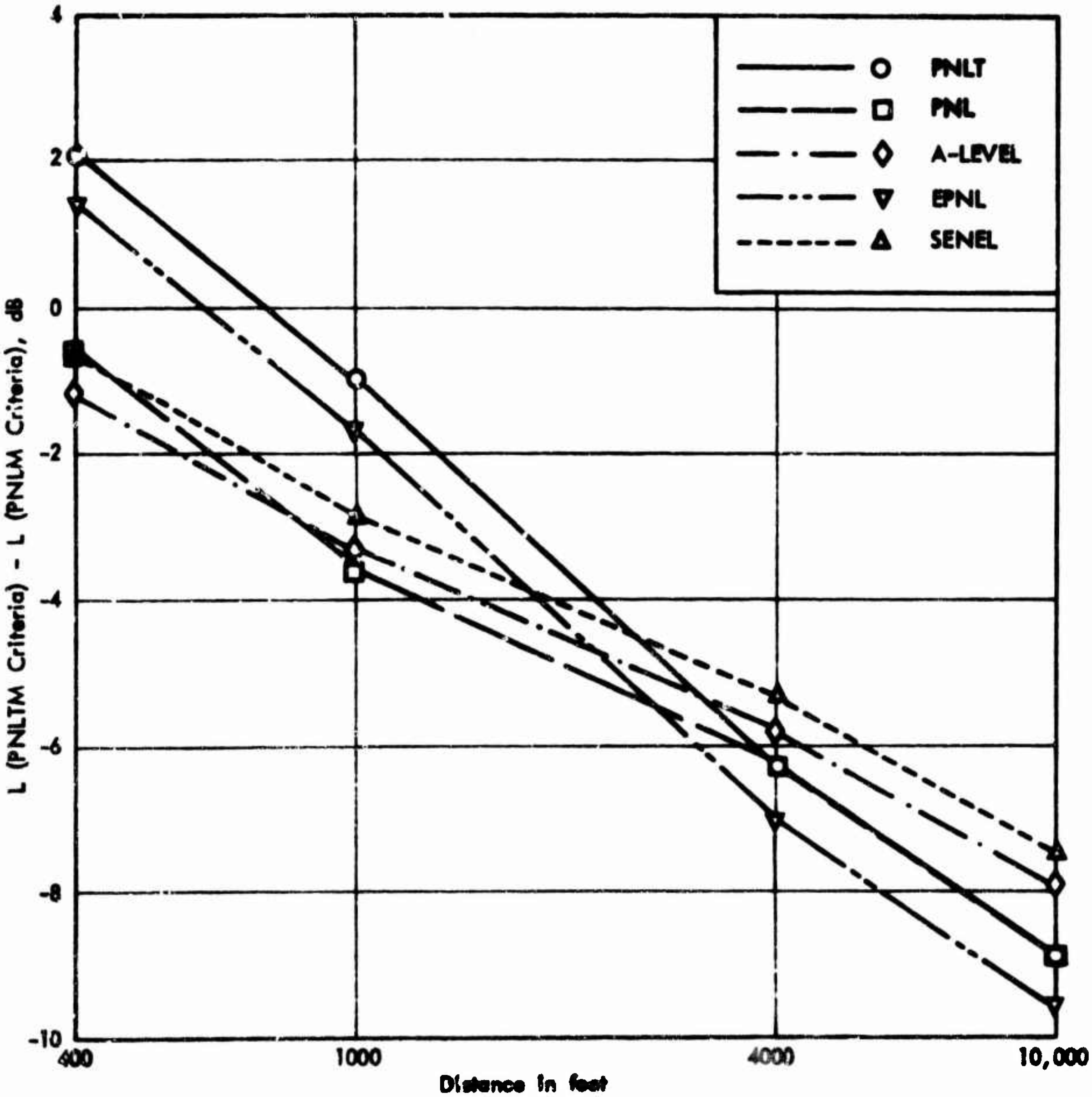


FIGURE E-15. DIFFERENCES IN NOISE LEVELS AT VARIOUS DISTANCES FOR NOISE CURVES SELECTED ON BASIS OF PNLTM OR PNLM CRITERIA - C135A AIRCRAFT, CRUISE THRUST, 160 KNOTS

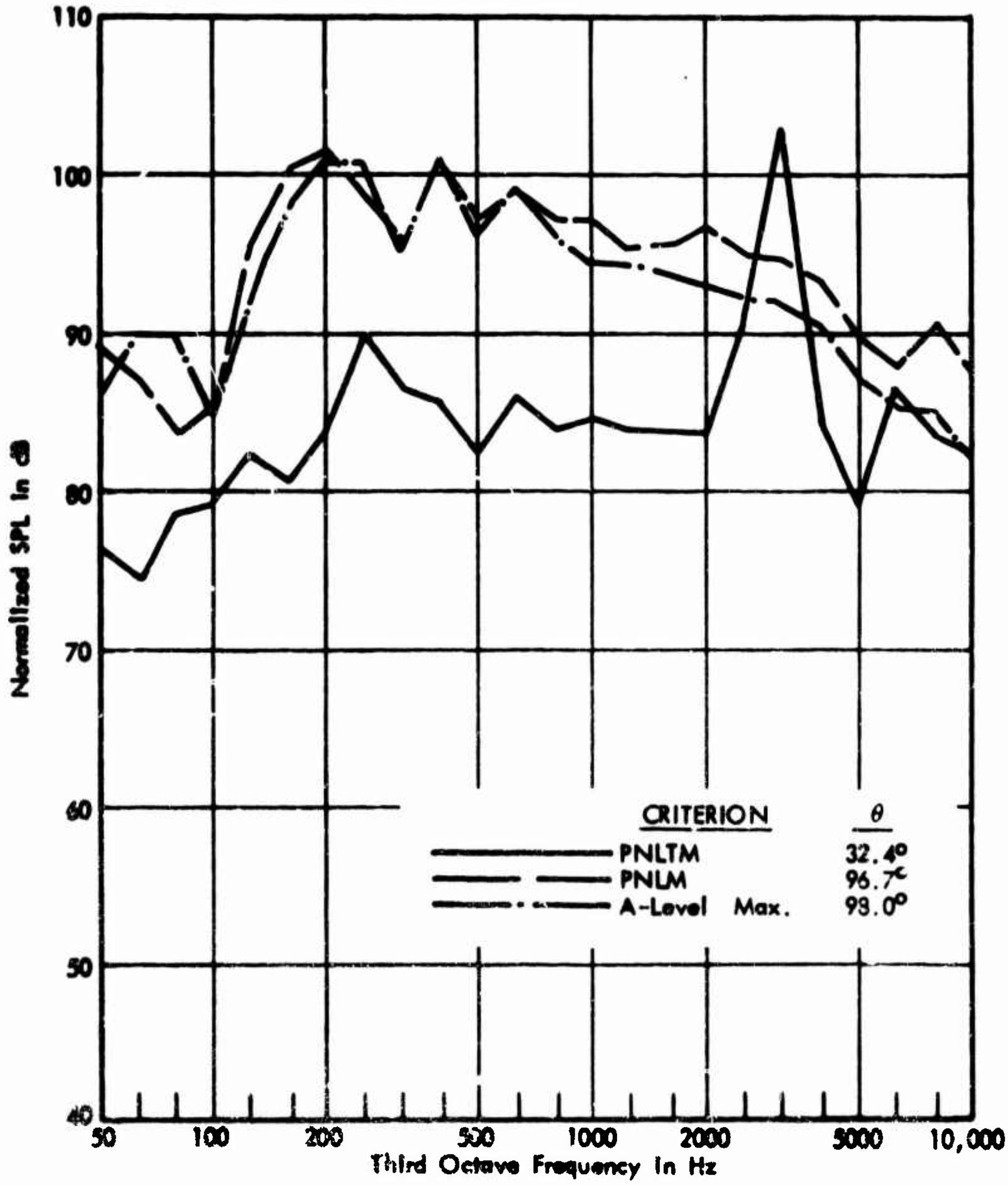


FIGURE E-16. NORMALIZED FLYOVER NOISE SPECTRA AT θ - C135A, APPROACH THRUST, 400 FEET, 160 KNOTS (SINGLE RUN 72-026-004-04)

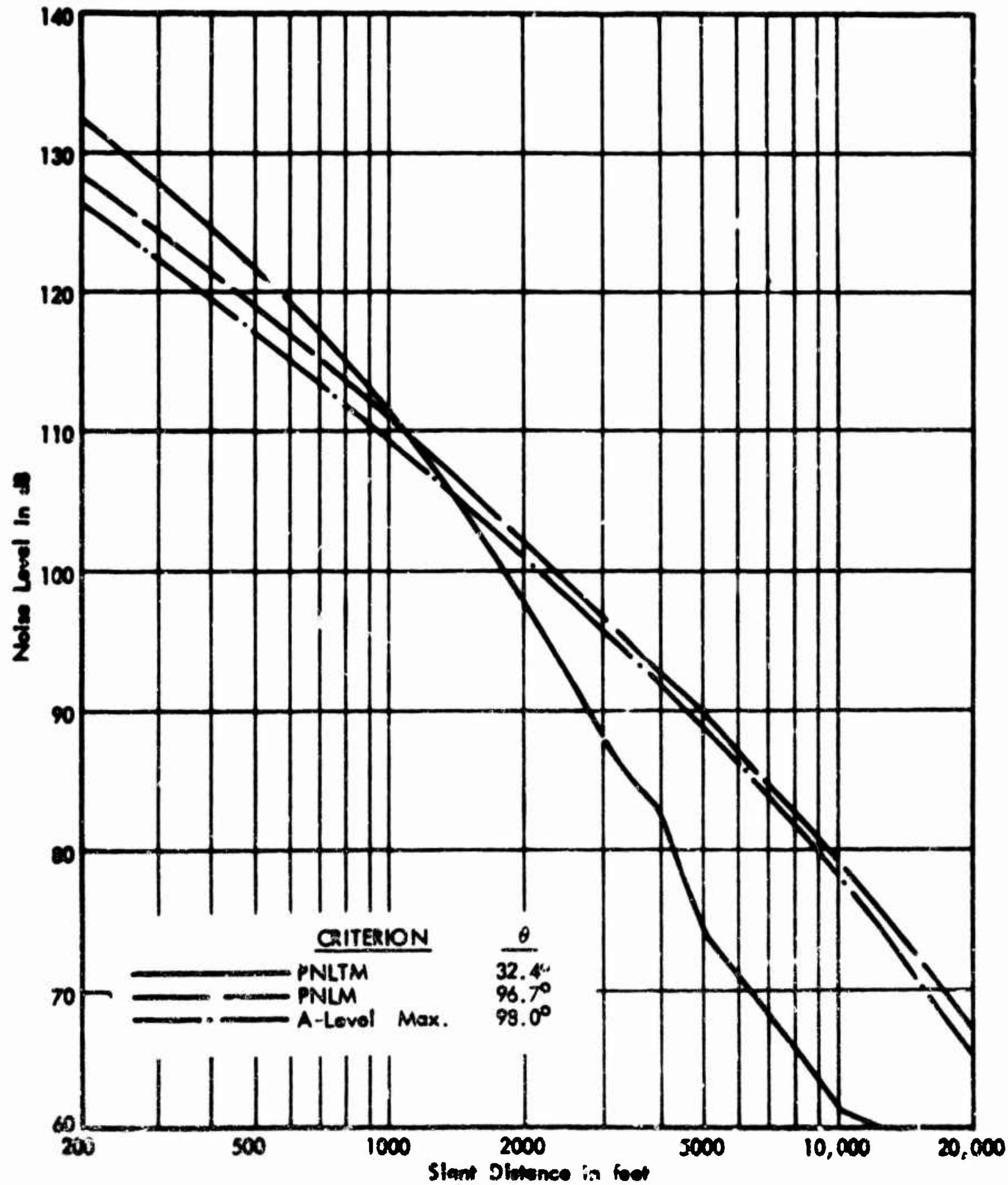


FIGURE E-17. TONE-CORRECTED PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS (SINGLE RUN 72-026-004-04)

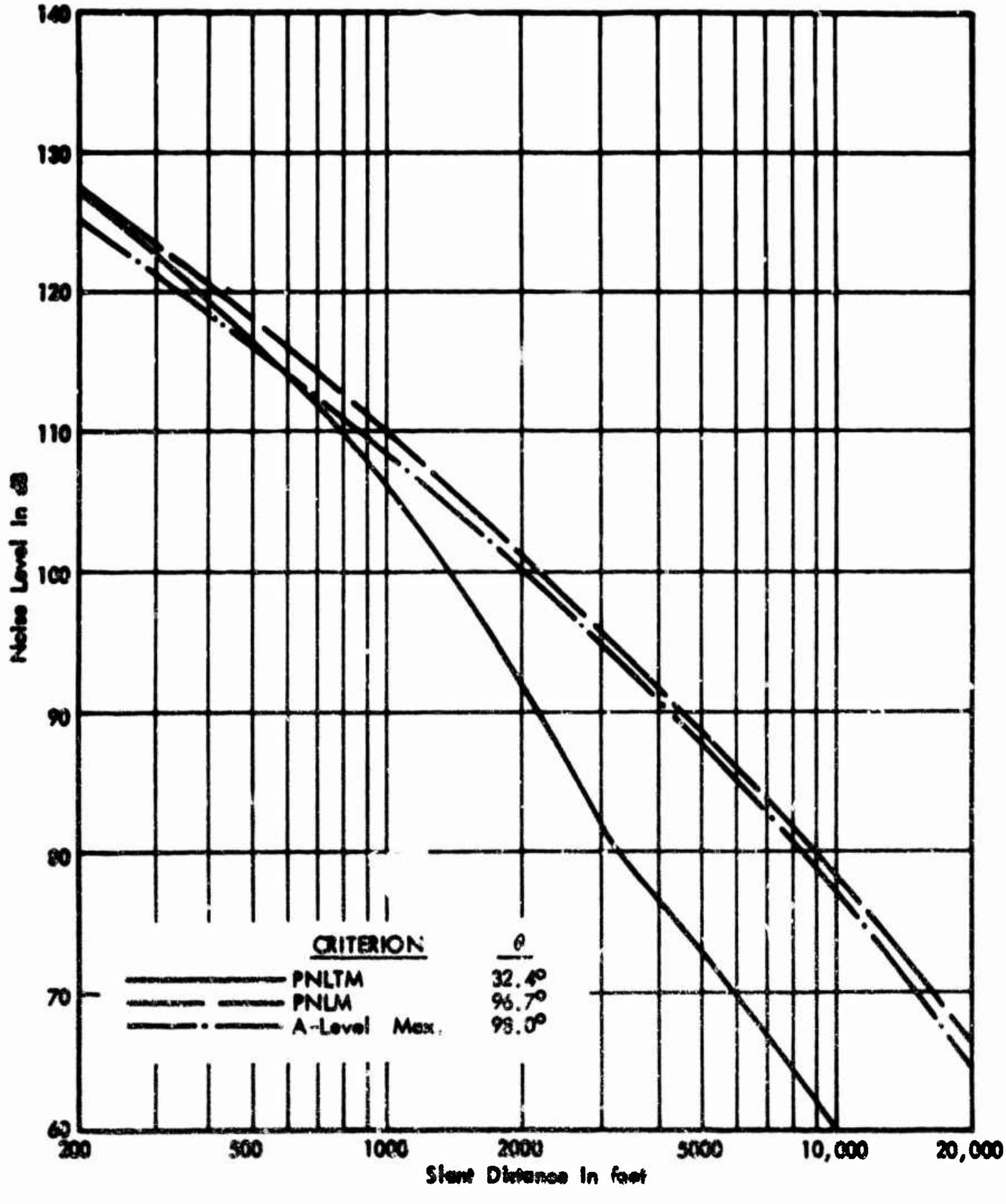


FIGURE E-18. PERCEIVED NOISE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS (SINGLE RUN 72-026-004-04)

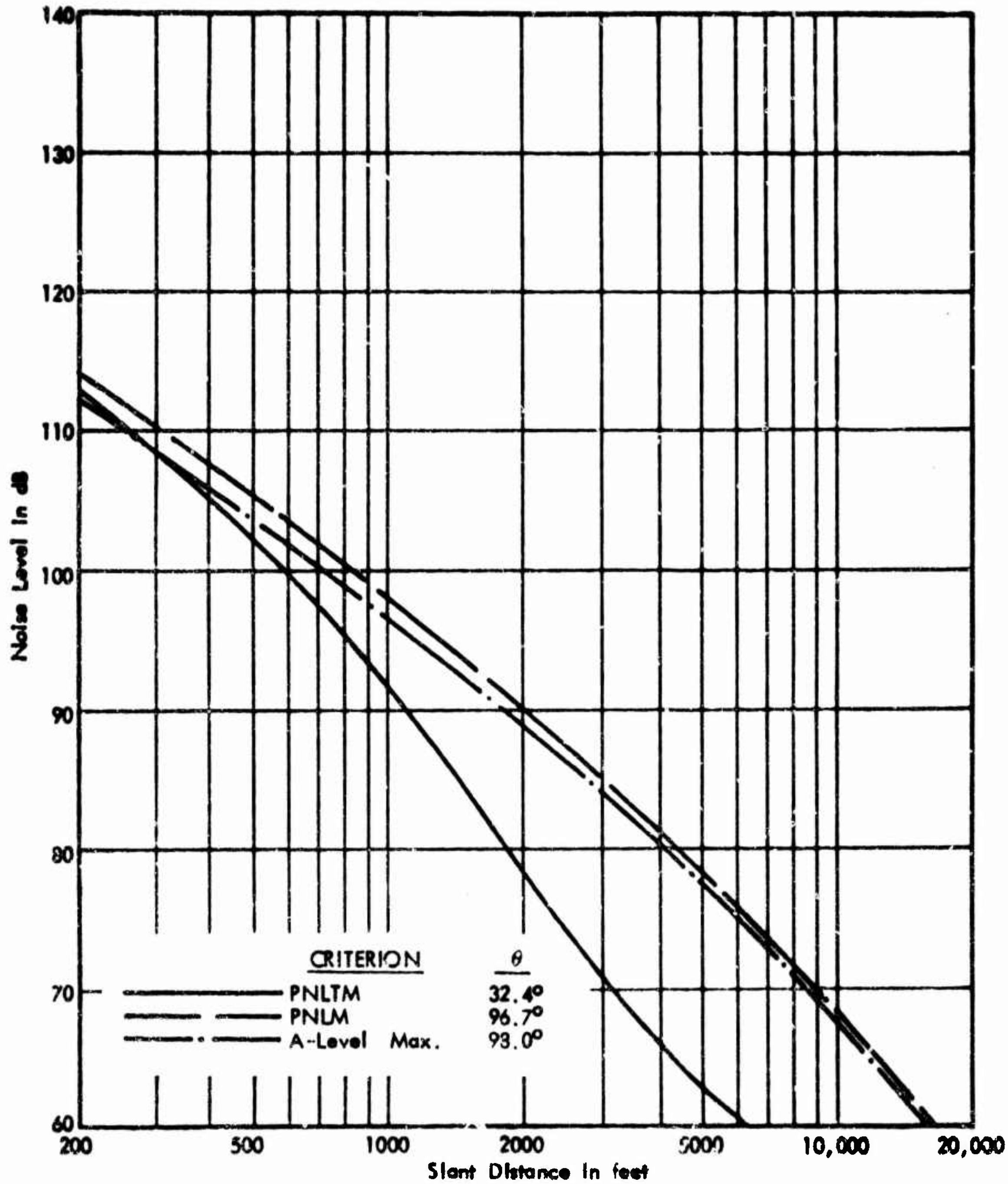


FIGURE E-19. A-LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA C135A, APPROACH THRUST, 160 KNOTS (SINGLE RUN 72-026-004-04)

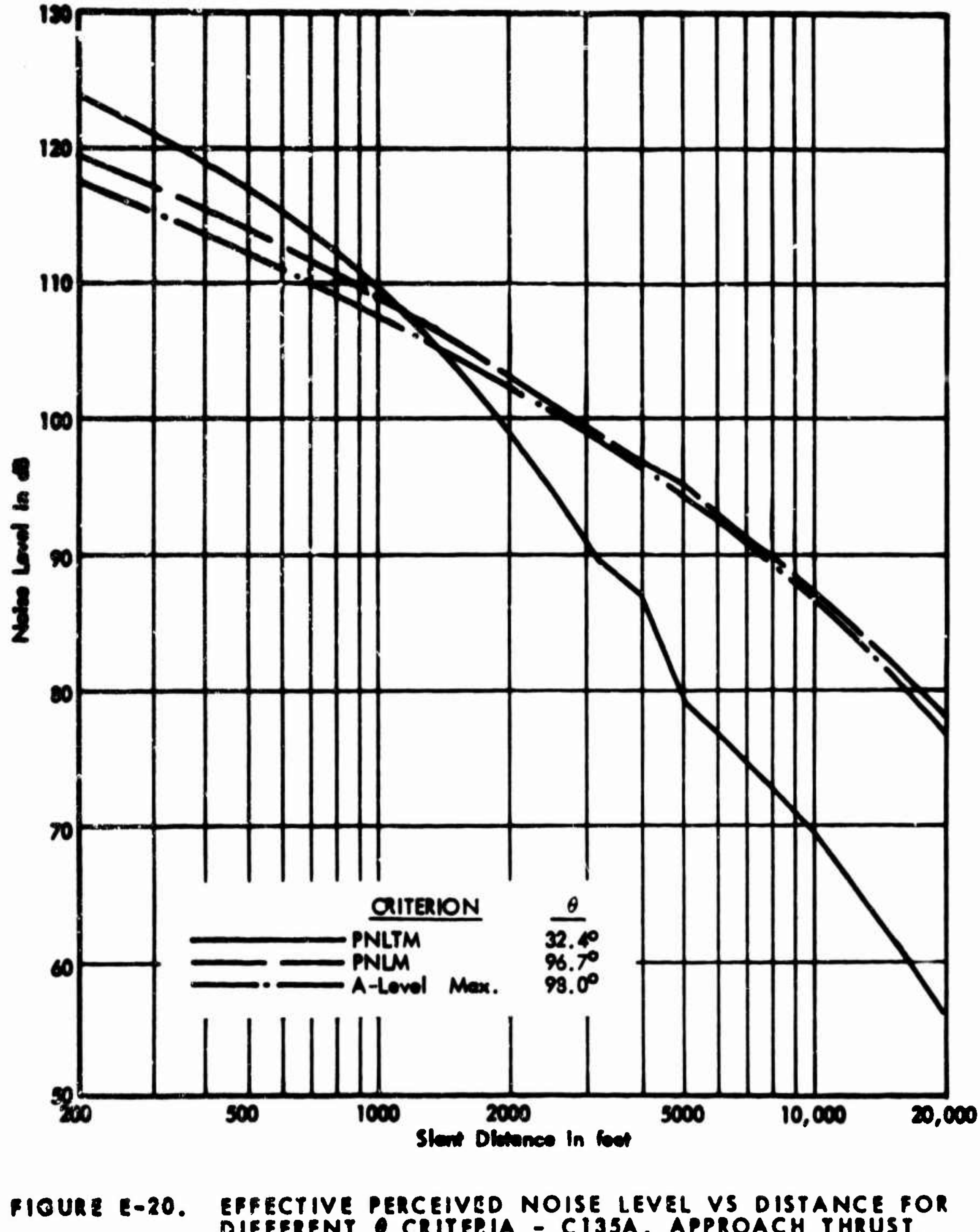


FIGURE E-20. EFFECTIVE PERCEIVED NOISE LEVEL VS DISTANCE FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS (SINGLE RUN 72-026-004-04)

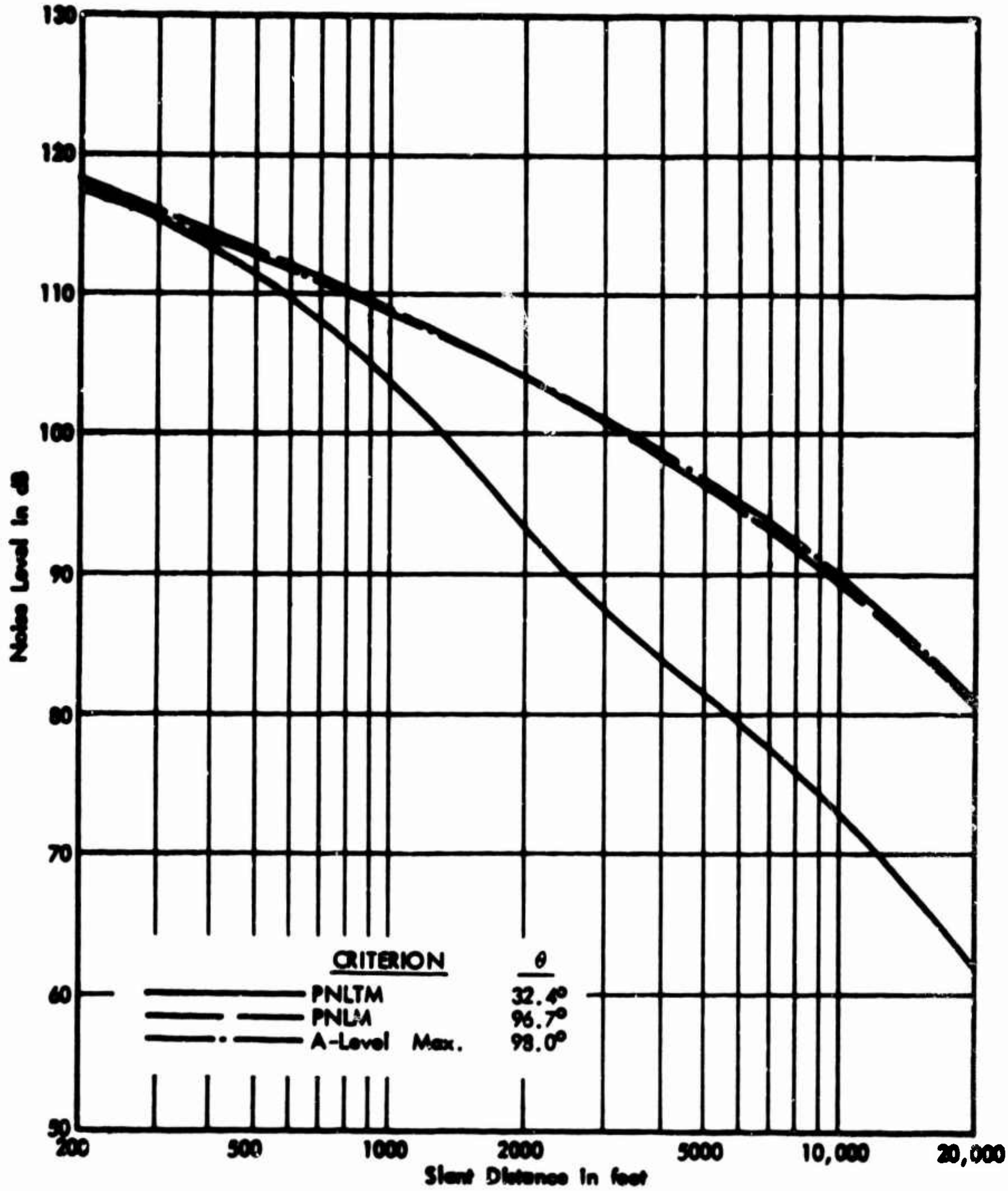


FIGURE E-21. SOUND EXPOSURE LEVEL VS DISTANCE CURVES FOR DIFFERENT θ CRITERIA - C135A, APPROACH THRUST, 160 KNOTS (SINGLE RUN 72-026-004-04)

APPENDIX F

DERIVATION OF EQUATION FOR THE DIRECTIVITY ANGLE AND SLANT DISTANCE, KQ, OBTAINED AT THE TIME OF MAXIMUM NOISE LEVEL

Referring to Figure 1, the actual directivity angle, θ, at the time of PNLM* is a function of the speed of the aircraft. The airplane has speed v in ft/sec, and is observed on the ground to have its PNLM occur at point Q, having travelled a distance v Δt from the overhead position at K. Actually, PNLM occurred sooner, at point Q', since the sound emitted at that time took a finite time interval to reach the ground at point K. The actual θ can be derived as follows:

$$\Delta t' = \Delta t - \frac{x}{c}$$

$$x^2 = h^2 + v^2(\Delta t - \frac{x}{c})^2$$

$$= h^2 + v^2\Delta t^2 - 2v^2\Delta t\frac{x}{c} + \frac{v^2x^2}{c^2}$$

or

$$x^2(1 - \frac{v^2}{c^2}) + \frac{2v^2\Delta tx}{c} - (h^2 + v^2\Delta t^2) = 0$$

Taking the positive square root,

$$x = \frac{-\frac{2v^2\Delta t}{c} + \left\{\frac{4v^4(\Delta t)^2}{c^2} + 4\,(1 - \frac{v^2}{c^2})\,[h^2 + v^2(\Delta t)^2]\right\}^{1/2}}{2(1 - \frac{v^2}{c^2})}$$

$$= \frac{-\frac{v^2\Delta t}{c} + [h^2(1 - \frac{v^2}{c^2}) + (v\Delta t)^2]^{1/2}}{\left(1 - \frac{v^2}{c^2}\right)}$$

*Or other noise measure used as the criteria for determining the maximum angle of radiation. (See Appendix E).

where x is the slant distance KQ'.

Since θ is given by $\sin^{-1} \frac{h}{x}$,

$$\sin \theta = \frac{h\left(1 - \frac{v^2}{c^2}\right)}{\left[h^2\left(1 - \frac{v^2}{c^2}\right) + (v\Delta t)^2\right]^{1/2} - \frac{v^2 \Delta t}{c}}$$

At speeds less than 150 knots, for directivity angles from 30 to 60 degrees, the error introduced by not including propagation time is an underestimate of the actual noise level by less than 0.5 dB. At a speed of 300 knots the underestimate is as much 1.3 dB. If one assumes the accuracy of measuring Δt is $\pm$ 0.25 seconds in obtaining the closest 0.5 second interval in Δt, not applying propagation time corrections will underestimate the true level by 1.6 dB, while applying them would leave a possible error of less than 0.3 dB.

In normal practice the directivity angle will be reported as 180 degrees - θ, i.e., the angle made as measured from the nose of the aircraft.

APPENDIX G

DERIVATION OF SLANT DISTANCE TO AIRCRAFT, ASSUMING THE DIRECTIVITY PATTERN IS CYLINDRICALLY SYMMETRICAL

Referring to Figure 3 :

$$(LP)'^2 = d^2 + h_1^2 \cos^2 \gamma$$

$$LX = \frac{LP'}{\sin \theta}$$

$$LX = \frac{\left[d^2 + h_1^2 \cos^2 \gamma\right]^{1/2}}{\sin \theta}$$

And, directly under the flight path, $d = 0$. For level flight, $\gamma = 0$. If $\sin \theta$ remains constant, it is convenient to plot EPNL as a function of the distance of closest approach to the flight path. The effect of climb angle may be ignored, within 0.5 dB, up to $\gamma = 28$ degrees. In this case, EPNL may be referenced to the slant distance to the aircraft track, at the distance of closest approach determined solely from $LX = [d^2 + h_1^2]^{1/2}$.

APPENDIX H

GROUND REFLECTION EFFECTS

The analysis procedures given in this test plan do not correct for ground reflection effects resulting from reflection or absorption by the ground. Such effects can disturb the spectrum shape by introducing spectral irregularities due to interference between sound directly radiated from the source and that reflected from the ground. The spectrum irregularities can introduce errors in computed noise level measures (such as the PNL, and in the tone corrections applied in computing PNLT). Reflection effects are particularly evident in ground-to-ground measurements (ground runup measurements for example) but are usually somewhat less evident in the air-to-ground data encountered in flyover noise analysis. Ground reflection effects are not included in the current procedures for the following reasons:

1. Although the phenomenon is quite well understood on a theoretical basis, simple well-developed and tested engineering methods for adjusting for this effect have not been established.

2. The influence of such ground reflection effects usually introduces relatively moderate or small errors for most cases of interest.

3. Ground reflection effects may introduce sizable errors in cases where one wishes to predict flyover noise levels from measured engine ground runup data. This estimation procedure is not employed in the current test analysis, hence this problem is avoided.

Where it is felt desirable to correct ground runup data for ground reflection effects, a first-order correction for broad band noise (jet noise, for example) may usually be accomplished by "hand smoothing" the frequency spectrum. This procedure, together with more elaborate test and/or correction procedures, are described in draft SAE AIR 1327 "Acoustic Effects Produced by a Reflecting Plane", 1974 or the latest revision thereof.

Ground reflection effects can also be experimentally "smoothed" using spatial averaging techniques by energy averaging the sound pressure levels over ground - microphone heights of 2 to 10 feet.

APPENDIX I

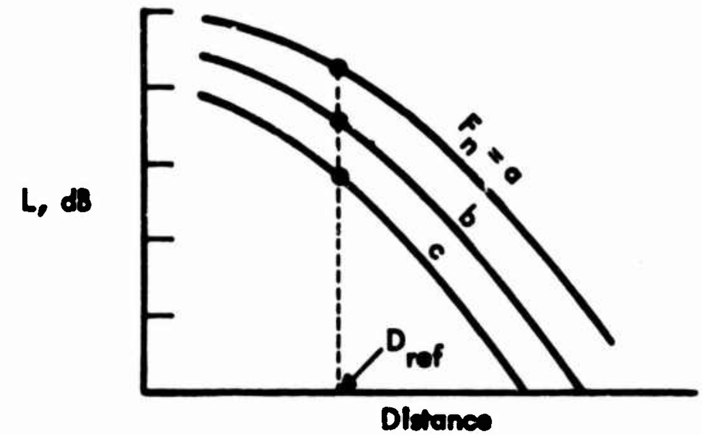
ENGINE THRUST ADJUSTMENT TO NOISE LEVELS

In Sections 10 and 11, a factor, Δ_6 in dB, is introduced to permit adjustment for differences in noise levels resulting from differences in engine thrust or engine power output. This factor may be introduced to correct field flight data to reference thrust conditions (Sections 10.2 and 11.1). Later, this factor may be used to adjust from reference thrust conditions to other specified conditions (Sections 10.5 and 11.4). This appendix outlines one of the ways in which the adjustment may be determined, with specific reference to turbojet and turbofan engines.

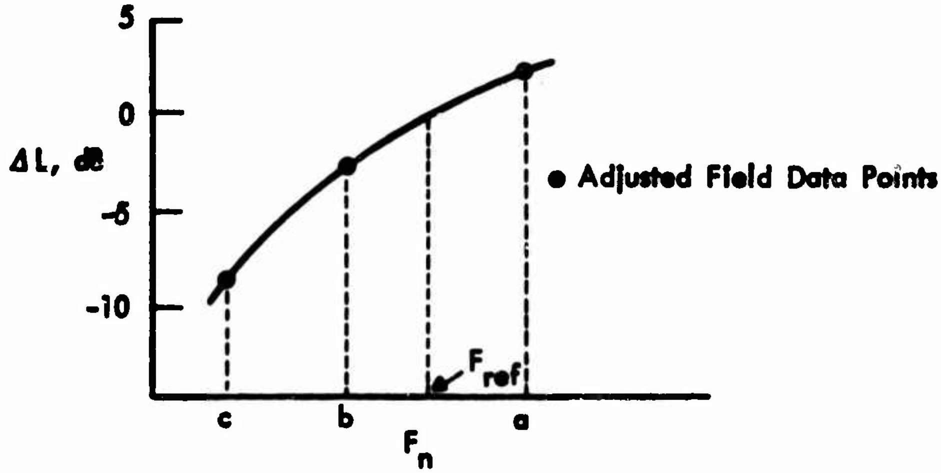
To determine the adjustment values in terms of practical aircraft operating parameters, several steps are generally necessary. The first step involves the assembly of sets of noise level (SELT, SEL, EPNL, etc.) vs. distance curves at different thrusts adjusted to standard day conditions and a reference airspeed, as shown in the upper portion of Figure I-1. The second step consists of plotting the noise levels at a given reference distance versus a basic engine parameter. Probably the most useful parameter for turbojet engines is the net thrust. As indicated schematically by the graph in the center part of Figure I-1, a curve can be fitted to data points to show the variation in noise level with net thrust. This curve can be used directly when net thrust information is available or can easily be calculated. This would usually be the case when one wants to make adjustments for changes in basic temperature or altitude conditions.

However, for adjustments in noise data to fit operating conditions for a specific air base, the noise versus thrust case should be translated in terms of the engine parameter that would actually be used by pilots and displayed in the aircraft cockpit.

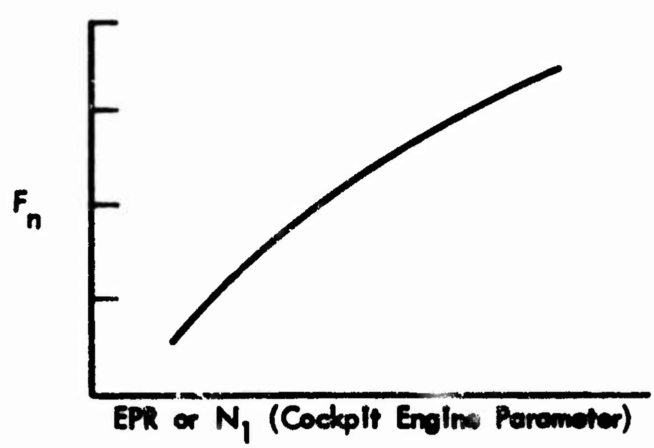
This translation is indicated in the lower part of Figure I-1. From this plot, one can then utilize practical engine operating parameters to determine the Δ_6 value.



① BASIC NOISE LEVEL CURVES FROM FIELD MEASUREMENT AT DIFFERING ENGINE THRUST ADJUSTED TO REFERENCE AIRSPEED AND STANDARD DAY CONDITIONS



② NOISE POWER PROFILE AT REFERENCE DISTANCE



③ ENGINE POWER PROFILE

FIGURE I-1. DATA NEEDED TO DETERMINE ENGINE THRUST ADJUSTMENTS

APPENDIX J

GROUND-TO-GROUND PROPAGATION NOISE LEVEL ESTIMATES FROM INFLIGHT AIRCRAFT NOISE MEASUREMENTS

Aircraft noise levels measured to the side of the runway during aircraft takeoffs or measured at low angles of incidence from aircraft in flight typically are significantly lower than levels estimated from flight measurements (with aircraft passing overhead) assuming only atmospheric air attenuation. Even when the excess ground attenuation provided in Figure 4 is taken into account, measured levels are often significantly lower than predicted.

The differences between measurements and predictions may be ascribed to several factors. Among them are the following:

(a) Ground reflection and absorption effects caused by finite impedance of the ground

(b) Engine noise source shielding produced by the aircraft airframe

(c) Excess ground attenuation that is greater than the values given in Figure 4

(d) Attenuation due to partial (or complete) shielding of the aircraft source by intervening buildings, terrain irregularities or trees and shrubs

In addition to the above factors, one also observes changes in sideline noise levels during the takeoff run which may be ascribed to changes in aircraft noise output and changes in signal duration due to the aircraft acceleration.

Analytic noise prediction models are not yet available that consistently agree with the available sideline noise data or noise data measured at near-grazing angles from aircraft in flight. Hence, in order to provide realistic estimates of "sideline" noise levels or levels at low angles of incidence, the following empirical procedure for estimating noise levels for ground-to-ground propagation is recommended. The procedure involves two basic steps:

(a) Provide for excess attenuation using the values of Figure 4. Typically, these values result in excess attenuation for calculated noise levels at distances greater than 1,000 ft. but negligible excess attenuation at shorter distances.

(b) Provide an additional attenuation factor to apply to all distances. Based on analysis of sideline noise data, weighted noise levels, such as the AL, PNL, EPNL, SEL and SELT show additional losses of from 4 to 8 dB. One-third octave band spectrum levels show wide variations, with quite pronounced frequency effects. However, rather than attempt to account for these frequency effects at this time, it is recommended that 5 dB be subtracted from all one-third octave band SPL values, and weighted noise levels be calculated from the resulting spectrum levels.

The above recommendations are applicable for prediction of noise levels for ground-to-ground propagation conditions from the takeoff position and beyond. They are also applicable for estimating approach noise down to the point of touchdown.

An additional adjustment is needed to account for the decrease of noise during the takeoff roll. In the current NEF/DNL programs, this adjustment is entered as part of the coding for individual aircraft and does not form part of the basic noise data file. For current military aircraft, this adjustment, applied as an offset to the weighted noise level curves (EPNL, SEL and SELT) is 4 dB specified as a 4 dB decrease in levels from brake release to liftoff.